



## Science teachers' narratives on motivation and commitment

*A story about recruitment and retention*

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## **PART 13: IN-SERVICE SCIENCE TEACHER EDUCATION**

Co-editors: *Jouni Viiri and Digna Couso*

In-service science teacher education, teachers as lifelong learners; methods, innovation and reform in professional development; evaluation of professional development practices, reflective practice, teachers as researchers, and action research.

This part corresponds to strand 13. It contains 32 papers.

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# **NANOSCIENCE AND NANOTECHNOLOGIES EDUCATION : TEACHERS' KNOWLEDGE**

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*Abstract:* “Nano Education” is an emergent field of research, in line with research in nanosciences and nanotechnologies. Curriculum design to integrate nano in education, from kindergarten to university is also an intense field of interests. Recent efforts have been devoted to document students understanding on nanoscale, to develop and implement innovative “nano” devices for teaching and to train science teachers on nano. In this paper, science teachers understanding of nano and intentions to teach nanos were investigated in the context of a summer school. Pre and post questionnaires were used. Categories were elaborated by an iterative coding process. Pre-post tests comparison of teachers' knowledge show that nanoscience and nanotechnologies mostly defined a minima by the nanoscale size in the pre-test were also apprehended with specific physical properties and applications in the post-test. Teachers tend to favor specific designed teaching activities to integrate nanoscience and nanotechnologies in class. Results also suggest an openness to curriculum activities in relation to educative aims broader than science concepts learning. Teachers intentions show extra-discipline based curriculum activities with educative aims in relation to an understanding of science in the making, argumentation, information literacy and citizenship education. This encourages to develop science education research linked to the design of teaching activities on a nano-literacy.

*Keywords:* Nanosciences - Nanotechnologies - Secondary education - Curriculum development - Nanoliteracy

## **BACKGROUND, FRAMEWORK AND PURPOSE**

Nanoscience and nanotechnology are often presented as a new scientific revolution or a new frontier to overcome that would generate tremendous economical gains (Roco, 2003). They also raise debates in society related to health and environmental issues, ethical concerns associated to modification of human beings and transhumanism, social and political issues linked to individuals data security and discussions about science and technology developments in democratic regimes (Berube 2006; David & Thomson, 2008; Lemley, 2005; Shapira, Youtie, Porter, 2010; Sheetz, Vidal, Pearson & Lozano, 2005). In such a context of controversial science and technology developments, education is presented as the major mode of science-society relationships regulation. Recent review of literature on nanoscience education has showed four emergent domains of interest for curriculum development and science education research (Hingant & Albe, 2010) : curriculum contents, approaches and purposes for nanoscience education at all levels of schooling, students' representations of size and scale and particularly nanoscale, specific instrumentations for nanoscience and nanotechnology teaching, science teachers training in nanoscience and nanotechnology. In this latter emergent research topic, this paper aims to contribute to our understanding of science teachers knowledge and representations about nanoscience and nanotechnology and their integration in science teaching.

## RATIONALE

Literature on teachers professional development on nanoscience and nanotechnology has focused on the design and evaluation of training programs aimed to favour nanoscale science and engineering integration into teaching (Blonder, 2011; Daly, Hutchinson & Bryan, 2007; Hutchinson, Bryan & Bodner, 2009; Tomasik et al., 2009). Pre-post tests comparisons showed that teachers' knowledge improved a lot (Blonder, 2011; Tomasik et al., 2009) and two teaching strategies have been identified from teaching sequences produced by the teachers during training program : one consisted of integrating nano-related topics into the whole science curriculum and the other to add a specific nanoscience module into the curriculum (Tomasik et al., 2009). Teachers expressed more willingness to introduce an extension of the curriculum on nanoscience and nanotechnology rather than teaching a lesson on a completely new specific nano content (Daly, Hutchinson & Bryan, 2007). The introduction of nanoscale science into the curriculum is envisaged by teachers on a discipline base and interdisciplinary activities then seemed difficult to apprehend (Daly, Hutchinson & Bryan, 2007). Factors have also been identified for teachers' reasons to implement nanoscience lessons in class : relevance, student motivation, curriculum inflexibility, technical aspects and content knowledge (Hutchinson, Bryan & Bodner, 2009). Interviews with teachers showed that teachers were not at ease with students' questions in class and felt their scientific knowledge was not sufficient.

Teachers conceptions of nanoscale sizes have also been assessed by questionnaires and card sort tasks (Jones et al. 2008). Results showed that experienced and novice teachers' knowledge about small scale were poorly mastered. Experienced teachers better performed at nano-scale measurements than novice teachers. As we ever mentioned when reviewing literature, teachers nano related content knowledge needs research efforts (Hingant & Albe, 2010). In this context, the purpose of this paper is to document teachers' knowledge and intentions to teach nanoscience and nanotechnology. An empirical study was carried on before and after a one-week summer school on nanoscience and nanotechnology for French secondary science teachers.

## METHODS

The 2010 E2phy summer school was the tenth issue of a series of yearly events dedicated to science teachers from secondary and higher education. It emanates from a group of teachers and researchers from research institutions<sup>1</sup>, scientists and teachers unions<sup>2</sup> with the aim to promote scientific research, inform teachers of recent science developments and favor links between schools and research centers.

The 2010 summer school was focused on physics of the nanoworld. It included lectures on advanced domains in nanosciences, social impacts of nanosciences (ethic, health, toxicity, law, regulation-jurisdiction...) given by French researchers well-known in their respective fields, lab-work, visits of research centers and special events opened to a large public devoted to discussions on research in nanoscience and their societal impacts.

The science teachers attending the summer school knowledge on nanoscience and nanotechnologies and intentions to teach nanoscience and nanotechnology have been collected with pre and post questionnaires.

Questionnaires were structured into two parts : first on nanoscience and nanotechnologies and second on nano-education. First part consisted of five open questions (identical for pre and post tests) : According to you, what are nanoscience and nanotechnologies? What are the characteristics or specificities of nanoscience and nanotechnologies ? What do you think of the stakes, interests, strategies of research in nanoscience and nanotechnologies ?

Nanoscience and nanotechnologies developments raise debates, particularly on health and environment effects, did you hear about that ? According to you, what is debated ? What definitions of nanoscience and nanotechnologies do you give or would give in class ? Second part of the questionnaires consisted of four questions (identical for pre and post tests : What do you teach in nanosciences ? What curriculum contents do you think could be linked to nanosciences ? With what forms ? What finalities ?) and three additional open questions for the post-test to assess the summer school: what did you gain from the summer school ? What do you think you can integrate into your teaching ? On the opposite, what do you consider as poorly adequate for your teaching ?

125 questionnaires have been collected for the pre-test and 47 for the post-test. All answers were transcribed and coded with categories that emerged through 3 rounds of analysis. As a first step, two coders elaborated categories of answers independently, then confronted their categorisations to build consensus categories (second step). As a third step, the previously elaborated categories were revised through another round of coding. For statistical analysis, Sphinx software was used.

## **RESULTS**

### **Science teachers' knowledge and representations on nanosciences and nanotechnologies**

A large majority of teachers, both in pre and post-tests, consider that nanoscience and nanotechnologies are knowledge relative to the nanoscale, and for some teachers it is a new domain with specific applications. Characteristics or specificities of nanoscience and nanotechnologies from the teachers viewpoints also mostly concern the nanoscale then technological developments, and a link with quantum mechanics is underlined in the pre-test.

In the post-test, teachers also focused on new properties specific to this scale, raising technological difficulties and debates. Stakes and interests are focused in teachers responses to the pre-test on medicine, electronics and information technologies within the context of international competitiveness and on economical and social registers in the post-test.

Teachers were mostly aware of debates raised by nanoscience and nanotechnologies both in pre and post-tests. Teachers underlined mostly health, nano-particles toxicity and interactions with living organisms, and environment in a lesser extent in both pre and post-tests. Moreover in the post-test, they added legal, political, social and economical issues related to nanosciences and nanotechnologies. They underlined the absence of epidemiological results in the pre-test and mostly health and interactions with living organisms, and environment in a lesser extent in the post-test.

### **Science teachers' viewpoints on nano curriculum integration**

Definitions of nanoscience and nanotechnologies to give in class are mostly focused on the nanoscale size and linked to knowledge on atoms and molecules for both pre and post-tests, and on the idea of a new domain with specific applications and physical properties in the pre-test (more rarely in the post-test for the latter). No answers of lack of knowledge were present in the post-test.

A majority of the teachers declared that at that time they don't teach nanoscience and cited curriculum contents that could be linked to nanosciences :

- size and scale,
- chemistry notions,

optics and medicine applications for the most cited (both in pre and post-tests) and electronics and size and scale in the post-test.

High-school teachers were the ones who contributed the most to the answers on that question about curriculum contents.

Forms of teaching envisaged are specific educative activities dedicated to the exploration and documentation of a new scientific domain in both pre and post-tests. Specific lessons in the science class are also mentioned in the pre-test according to the finalities of showing science in the making, developing engagement in science and understanding of scientific concepts.

In the post-test, collaboration with research labs, debates and video presentations are cited within finalities of showing science in the making, developing engagement in school science, understanding of scientific concepts, contributing to information literacy, citizenship education and learning to debate.

## **Teachers' evaluation of the summer school**

In responses to the three additional open questions for the post-test, teachers expressed that from the summer school they gained knowledge on nanoscience and nanotechnologies and on nanoscience and nanotechnologies research, ideas for pedagogical activities and personal reflections. They considered that they can integrate informations and knowledge on nanoscience into their teaching.

## **CONCLUSIONS AND IMPLICATIONS**

Pre-post tests comparison of teachers' knowledge show that nanoscience and nanotechnologies mostly defined a minima by the nanoscale size in the pre-test were also apprehended with specific physical properties and applications in the post-test. This result on teachers knowledge improvement through training programs converges with literature (Blonder, 2011; Tomasik et al., 2009). Teachers tend to favor specific designed teaching activities to integrate nanoscience and nanotechnologies in class. This result may converge with the previously identified teaching strategy of teachers privileging an extension of the science curriculum on nanoscience and nanotechnology (Daly, Hutchinson & Bryan, 2007) with reasons based on relevance, students motivation and content knowledge (Hutchinson, Bryan & Bodner, 2009). It also differs from literature stating a discipline base in teachers intentions (Daly, Hutchinson & Bryan, 2007) and on the opposite suggests an openness to curriculum activities in relation to educative aims broader than science concepts learning. This encourages to develop science education research linked to the design of teaching activities on a nano-literacy.

## **NOTES**

1. National Institute of Nuclear and Particle Physics (IN2P3) of CNRS (National Center for Scientific Research, a government-funded research organization, under the administrative authority of France's Ministry of Research); French Atomic Energy Commission, leader in research, development and innovation, with the objective to ensure that the nuclear deterrent remains effective in the future.
2. The French Physics Society, association that aims to promote physics and physicists. Physics and chemistry teachers union, Teachers union in the French specific two years undergraduate programme leading to a nation-wide competitive examination into a French

"Grande école", leading schools in engineering, management, research... The scientific programme includes high level courses in mathematics, physics, chemistry, computer and engineering sciences, as well as humanities (foreign languages and philosophy).

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# **SCIENCE TEACHERS, POLICIES AND EDUCATION RESEARCH. ANALYSIS OF SURVEYS CONDUCTED IN SIX COUNTRIES**

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*Abstract:* It is broadly agreed that the relationship between teachers’ beliefs and science education research results is complex and requires additional investigations and new approaches to understand the role of specific resources and constraints. Deeper investigation is needed concerning the distance among teachers’ feelings and expectations, the kind of educational research they know and the models of self-training that can be proposed in order to improve teacher knowledge and practice, supporting and focusing instruction in productive directions. The present research has been conducted, in the framework of the EU-funded TRACES project, in six countries (Argentina, Brazil, Colombia, Israel, Italy and Spain). Among all partner countries 1900 questionnaires were collected and 164 people (teachers, principals, researchers and policy makers) participated in interviews and focus groups. Findings from the comparison of the national surveys show the existence of tensions among all components of the education system. In the paper we analyze those concerning the relationships (and distances) of the school teaching from the national governance (guidelines, programs, assessment), on the one side, and educational research on the other side. Discussing the results we want to make a contribution to identify strategies and methods of investigation to figure out how to get answers to open questions of research that have not yet been sufficiently investigated.

*Keywords:* research-to-practice gap, evidence-based teaching, teachers’ beliefs, school system, education policies

## **BACKGROUND AND PURPOSE**

An accumulating body of literature suggests that the gap between research itself and practice in science education is wide and rooted in a complex system of factors. In particular, we know that although teachers regard research evidence as valuable for they work, they are reluctant to adopt change if evidence does not resonate with their conceptions, beliefs and professional experience. The contribution we propose is the result of an international survey focused on the relationship between research and practice in science education undertaken in the framework of the TRACES project (see [www.traces-project.eu](http://www.traces-project.eu)), in which Italy, Spain, Israel, Brazil, Argentina, Colombia are involved. We use the findings from our surveys to identify key factors in the research-practice gap and suggest open issues and the way to address it in further research on the subject.

## **RATIONALE**

Although it is well known that a deep gap separates educational research findings and real world school practice, research base about the links between aspects such as students performance and teachers’ preparation, beliefs and teaching approaches, resources available, interaction with principals, colleagues and pupils’ families, role of policies and curricula is still disparate and uneven (NRC, 2010; Lederman, 1999; Mellado, 1998). We know that

research is crucial for improving science education (Duit, 2006). On the other side, fostering evidence-based change in teaching practice implies resonating with teachers' professional experience and beliefs about science education (Ratcliffe, 2005). Research findings are not likely to have an impact if they are not perceived as consistent with real-world practice conditions, such as availability of resources, average number of students per class, curricular constraints, teachers' pre- and in-service training. Bridging the research-practice gap in science education and sustaining the ongoing improvement in teaching and learning requires therefore more extensive investigation into all such aspects of the teaching reality. Recommendations and research agendas about a number of open questions for what regards improving evidence-based science teaching have been proposed in the literature (Osborne, 2008; NRC, 2010; NRC 2007). Further research is need on issues such as the relationship between different systemic factors in science education; how practice is influenced by policies, research and societal factors; how much policies are informed by research; how research-informed teaching improves students' performance; what is the role of teachers' beliefs and of their conceptions of science and pedagogy; what is the role of the context; what are the conditions that sustain or hamper effective teaching (see e.g. NRC 2011 and references therein).

## METHODOLOGY

Our data include answers to a questionnaire administered to thousands of teachers in the six countries involved in TRACES and interviews and focus groups conducted with a smaller scale sample population of teachers, principals, policy makers, teacher educators and researchers in science education. The questionnaire includes both closed and open questions. A common form of the questionnaire was agreed at the consortium level. The common questionnaire was then localised – not simply translated – for application in each partner country. We considered that mere translation, rather than guaranteeing better comparability, would have provided less reliable data. In each partner country, some of the questions were adapted to the local context in order for the target group to understand their meaning as it was originally intended at the consortium level. The complete common questionnaire (in English) can be found in appendix to the report D3.1 on the TRACES website. The localised versions of the questionnaire can be found in the D2.1-6 reports. Our large-scale data include 1900 completed questionnaires, while on the small scale 164 people were involved. The detailed record per country is shown in Table 1.

	Argentina	Brazil	Colombia	Israel	Italy	Spain	Tot
Questionnaires	479	145	215	64	790	207	1900
Interviews / FG's	11	29	30	34	45	15	164

**Table 1. Small- and large-scale survey samples in each partner country**

Questionnaires have been assumed as the primary source of information, while interviews and focus groups represent a follow-up study, allowing for a deeper interpretation of the results emerging from the questionnaires. The comparison of the national surveys data started from identifying analogies and differences in answers to the teachers' questionnaire. The chart in Fig. 1 represents the overall answers to one of the core questions in the questionnaire (Q8: "In order to improve teaching and learning of science at school, do you think the following actions are?"), with agreement-disagreement with each item in the multiple choice measured on a 4-grade Likert scale.

As the chart shows, the majority of the teachers perceives all items in the multiple choice as at least relevant in order to improve science teaching, so expressing a strong need for structural changes in their extant practice. Nevertheless, a ranking in the importance attributed to the different actions is also quite evident. This ranking was quantitatively tested according to the



non-parametric Mann-Whitney U-test. The main emerging issues can be summarized as follows:

- Little relevance attributed to changes in curricula and official guidelines (item 1);
- Little relevance attributed to changes in the assessment criteria (item 3);
- Strong need for circulation of ideas and resources, but not for the involvement of external actors (items 2,8,9,10);
- Strong need for material resources and in particular for lab facilities (items 11,12).

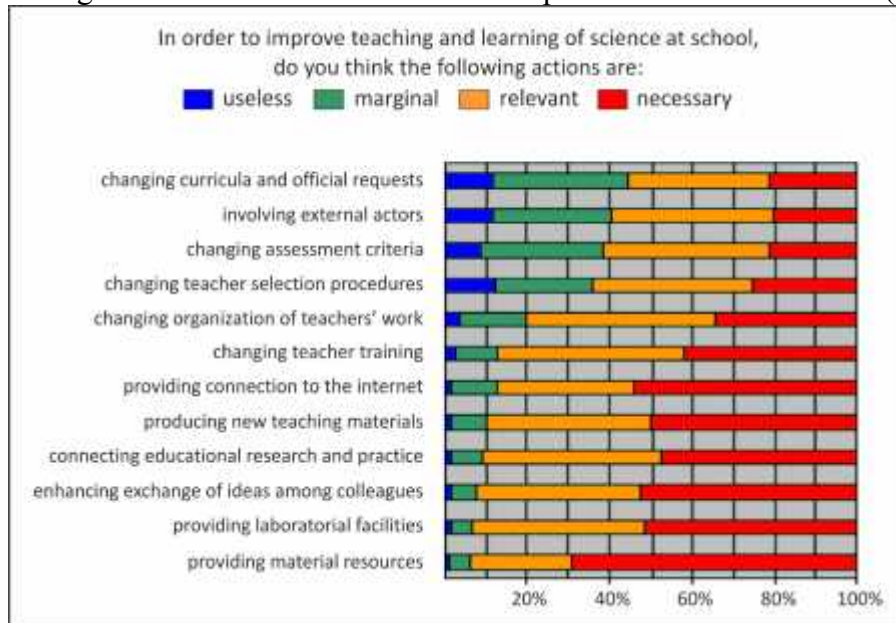


Fig. 1 Overall answers to Question 8 (large-scale sample)

These issues have been considered as emerging indicators of the tensions between teaching practices and policies (a., b.) on the one side and teaching practice and science education research (c., d.) on the other. Comparison of the qualitative data from interviews and focus groups allowed for a deeper insight into stakeholders' perspectives about elements a.-d. and an interpretation of the reasons of their emergence. In order to analyse these data, a qualitative content analysis approach based on text coding has been used.

## RESULTS

In this paper, we discuss issues a.-d. listed in the previous section on the basis of findings from the main categories (occurrence above 10%) emerging from our text-coding analysis of qualitative data.

### *Tensions between educational policies and teaching practice*

Teachers expressed low interest in “changes to the official requests” as a means for improving science teaching (a.). With slight differences in percentages from country to another, this item was one of the less valued in all our surveys. The emerging picture is confirmed when one cross compares these answers with those to Q1 (sources of the important ideas for science teaching) and Q9 (sources of ideas to improve teaching practice), in which the item “official documents” is very poorly represented (by far the less mentioned item with frequency lower than 10%).

In teachers' perspectives, the little relevance attributed to changing official requests is correlated to a number of factors. Teachers perceive a deep separation between the contents and goals of official documents and the real-world working conditions. Mostly, this is expressed with regard to lack of adequate time and material resources in order to fulfil the

requests, or in terms of incapability of meeting students' needs related to a specific socio-cultural context. This remark is often connected to the lack of involvement in the design or evaluation of policies, referred to as one of the elements contributing to create the gap with the actual teaching practice.

Moreover, even if some teachers do value the rationale of official indications they often mention an absence of correspondent adequate training programmes. All the national surveys highlight teachers' general need for more specific training in order to be able to manage the contents of science curricula. Lack of specific training programmes developed to support the latest science education reforms is also referred to in almost all the involved countries. The perceived inadequacy of preparation often leads to a difficulty in complying to the official requests because they are poorly understood and hardly translated into practice.

The large majority of teachers seems to give prominence to practice as the main source of training (in the questionnaire, 77% of the sample indicates *professional experience* as the main source of inspiration for their teaching) and this habit is often translated into inertia in moving from a well-established practice based on experience and know-how.

Besides personal experience, a large majority of the sample in all countries referred to the enhancement of the exchange of ideas among colleagues as a strongly relevant change for the improvement of science teaching (Q8). This is also confirmed by answers to questions Q1 and Q9, in which colleagues are always referred to as one of the most valuable sources of ideas for science teaching.

At the same time, from interviews and focus groups emerges that the actual communication among teachers is often (perceived as) limited to issues related to the solution of organizational problems and institutional opportunities for dialogue usually do not foster a more significant interaction. Moreover, qualitative analysis (of both data from open questions in the questionnaire and from interviews and focus groups) suggests that the actual situation of practicing collaboration is rather more complex. Here, the attitude of everyone to question their own beliefs is considered as a necessary premise for a fruitful collaboration.

Another main issue emerging from the surveys is connected to structural barriers towards the improvement of science education that are characteristic of the national school organization. Among these barriers the more recurrent ones are the organization of teachers' work (mainly in terms of timetables), the lack of material resources, the lack of recognition and incentives, and the large number of students in the classrooms.

Interaction with school administrators is another point on which it is interesting to focus. Here, it is interesting to compare teachers' and principals' perception about structural issues. In both cases, a general perception of a strong lack of material resources emerges, with special reference to the lack of laboratorial facilities as crucial factor for the improvement of science teaching.

In all countries, principals also lament the lack of teachers' adequate preparation in scientific contents and teaching methodologies, together with the lack of motivation among teachers, which is seen as a factor opposing the implementation of innovation programmes. Teachers are seen as using out-of-date teaching approaches, mainly based on the use of textbooks as the main resource. The structural need for a better selection of teachers is connected to the limitations to their decision-making power.

The little relevance attributed to changes in assessment criteria (b.) is mainly correlated to negative perceptions of standardized evaluation tests. Indeed, a particular aspect in all stakeholders' perceptions – not only in the one of teachers – about the impact of official guidelines is connected with the introduction of standardized procedures for the assessment of learning, which is quite a topical issue in recent school reforms worldwide. There is almost

general agreement in teachers' negative perception of this kind of tests as long as they expose to the risk of shifting the focus of teaching/learning towards the achievement of good results in the tests.

*Tensions between science education research and teaching practice*

In teachers' perspectives, the strong need expressed for the circulation of ideas and resources for the improvement of science teaching often refers to the importance of exchanging experiences with colleagues, seen as a means for collective growth. At the same time, from the questionnaires a judgement of poor relevance emerges for what regards the involvement of external actors. This is expressed by the large majority of the teachers in the sample (see Fig.1) (c.). This perception is again in line with the strong relevance of "professional experience" as source of important ideas for science teaching emerging from answers to Q1.

Putting all these considerations together, a picture emerges of teachers having strong confidence in their personal teaching skills. On one side, this could imply that teachers are interested in carrying out research autonomously in their schools, as is suggested by the fact that many among both teachers and other stakeholders in our small-scale sample referred to school as the place where research in science education has mainly to be carried out. Another possible interpretation, though, might be that teachers see research finding mainly as teaching materials produced by research professionals they can profit from and use autonomously at school.

A finding that emerges clearly in all national surveys is that teachers would like to receive greater support from universities in order to improve their teaching practice. In teachers' answers to open questions in the questionnaire, and in interviews and focus groups, contact with research was frequently depicted as 'rare' or 'not common', while need was expressed for a stronger interaction between school and university. In fact, many teachers in our sample referred to research as a relevant transformational tool in their practice in the classroom, as it implies a direct impact on student learning. This is also confirmed by quantitative data on the relevance of enhancing "connection between practice and research" as a priority action in order to improve science education emerging from teachers' answers to Q8 (see Fig. 1). Nevertheless, we think deeper understanding is needed of the kind of contributions teachers expect from the interaction between school and university. At the same time, indeed, teachers often underestimate direct interaction with science education researchers, as is also evident from answers to Q8.

The reasons that are mentioned with highest occurrence refer to researchers' attitudes. Teachers depict researchers as lacking the capacity to actually manage the work in the classroom, mainly in terms of mediation strategies. Despite providing an important and necessary contribution in terms of disciplinary contents, researchers are seen as not having the necessary 'sensibility' for what concerns the dynamics of interaction and work with children. Moreover, one of the main and most widespread critical knots in the relationships between teachers and researchers seems lie in the teachers' vision that researchers are not sufficiently aware of school contextual matters and related constraints. Many teachers in our sample said researchers come to school in order to collect data for their publications and that scarce feedback is given for the school to actually be able to profit from.

When teachers refer to the importance of connecting their practice to the research evidence, they point out that their main interest seems to be directed towards educational tools and resources they can use autonomously.

By their side, researchers see the lack of interest towards collaboration as related to teachers' resistance towards didactic experimentation: teachers adopt innovation contributions only in very special situations, because experimentation leaves less room for the usual implemented curriculum, which is well inserted in the overall system and regulated by many factors, such

as higher grades standards or internal surveys.

Moreover, it seems that some topical themes of research in science education play little role in teachers' interests. Generally, teachers underline the necessity to root practice in inquiry-based activities and to increase the material resources therefore necessary (d.). More precisely, many teachers mention the necessity of basing science education activities upon "practical work" and underline the importance of increasing the material resources devoted to this kind of activity. Nevertheless, a widespread view is that laboratories are a special context in which non-ordinary activities can be carried out. The whole idea of good practice in science education seems to be centred on the necessity of 'practical', 'experimental', 'lab' activities. These connotations are recurrent both in answers to open questions in the questionnaire and data from interviews and focus groups. The vision good practice appears indeed to be weakly connected with an inquiry-based approach, suggesting a naïve interpretation of hands-on work by the side of the teachers. Experimental activities are described as strongly based on pre-defined procedures, being often reduced to the mechanical repetition of a standardized set of manipulations. They often lack of the direct participation of the pupils and aim more at obtaining 'correct results' than at comparing conflicting explanations or giving answer to any inquiry questions. This finding is in line with research conducted in other countries on science teachers' belief on and implementation of practical work (see e.g. Millar 2010 and references therein).

Our data also suggest another facet of teachers' perceptions of science teaching and learning. One that seems more aware of the cognitive aspects thereof. When asked about 'important ideas about science education' (Q1), teachers frequently refer to students' thinking and reflection and when asked about the 'most important goals of science education', the majority of them rank critical thinking above learning for becoming a scientist or science for citizenship. In the case of teachers sharing this vision, emphasis is placed on the importance for students to learn to think and explain the way scientists do. Considerations of this kind of are indeed common cross-context and cross-nation in our data. There are although a few teachers who explicitly refer to thought processes that have been treated extensively in research on teaching approaches, like for example significant knowledge or teaching for understanding.

## CONCLUSIONS AND DISCUSSION

Our analysis of a large amount of data collected in six countries as different as Argentina, Brazil, Colombia, Israel, Italy and Spain allows us to further detail some crucial open research questions and suggest specific aspects to look at in order to better understand the systemic features of the research-practice issue in science education. Findings emerging from our surveys highlight some of the factors underlying the tensions existing between three key components of the science education scenario: policies, research and practice. While some factors are common to the six countries involved, in other cases deeper insight is gained when comparing issues and strategies to address them in the different contexts. Based on our findings, we propose a research strategy for investigating open issues related to the research-practice gap. We suggest that an effective path is field research involving whole schools regarded as complex systems of interacting dynamics. In these programmes, teachers should be less the target of a ready-made intervention based on assumed research evidence than the protagonists of a participative process in which they work together with researchers as peers at all stages. Our findings sketch out a picture of teachers marked by a strong sense of isolation and scepticism towards policies and external actors entering the school. At the same time, a positive perception of research and innovation and a great need for change clearly emerge. Scepticism is a natural reaction when change is imposed top-down without debate, as

is mostly the case of policies in the countries involved in our surveys, or when the interests of those promoting the change (e.g. researchers) are perceived as distant from one's own. Our findings lead us to believe that an in-depth inquiry into factors contributing to school's resistance to change cannot be addressed without an active involvement of those expected to be effected by the change. Based on the findings of our surveys, we have drawn up a set of indications for devising researchers-teachers interactions aimed at implementing research-based teaching (the complete set of indications can be found in D3.1, see above). Our field actions (now almost at the end of their one-year span in over 50 schools) are confirming that building trust is a process of mutual understanding and recognition which is based on a constant dialogue and exchange and participative decision making. That flexible structure and open-ended approach allow for an understanding of teachers' needs and expectations and the factors constraining their everyday practice. That this process is necessarily situated and context dependent as long as acceptance is based on the recognition that actions implemented are relevant to one's own practice. These findings support and widen the idea of "resonance" between research and practice as a key factor for bridging the gap as was suggested by Ratcliffe et al. (2005) and the considerations about essential elements in effective professional development emerging from the CASE project as reported by Adey & Serret (2010). Many of our findings are corroborated by the insights emerging in the framework of TRACES from analyses from other partner countries and presented in the common ESERA symposium. In particular, conclusions drawn by Israeli and Brazilian colleagues confirm our vision of the tension among policies, research and practice in science education and the need for a more active involvement of teachers and schools in research and development programmes. The question whether the role of researchers and teachers in common R&D programmes should be firmly distinguished based on the consideration that their competencies are structurally different remained open at the end of the symposium, with researchers from both the symposium panel and the audience holding different positions on the matter.

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# **PRACTISING SCIENCE TEACHERS' VIEWS ON CORES AND ITS IMPACT ON THEIR PROFESSIONAL KNOWLEDGE OF PRACTICE**

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*Abstract:* This paper reports on a research project that explored the use of CoRes with in-service secondary and primary teachers in Australian schools. The two year longitudinal study investigated how these teachers ( $n = 6$ ) might *value* CoRes, after constructing and using them in their classrooms, and how the instrument might influence or develop their long term professional practice. In particular, the project explicitly explored how their PCK might be articulated, revealed or developed as a consequence. In constructing and using CoRes in their classrooms, all six teachers claimed that the CoRe was a considerably valuable instrument in helping them to frame their knowledge of practice more explicitly, that they began to articulate and form an understanding of their own PCK, and that the CoRe prompted them to meaningful reflect about their practice in more deliberate, conscious and effective ways.

*Keywords:* Content Representations (CoRes). Pedagogical and Professional-experience Repertoires (PaP-eRs). Pedagogical content knowledge. Science teacher education. Science teachers' knowledge.

## **BACKGROUND, FRAMEWORK AND PURPOSE**

Pedagogical content knowledge (PCK) has long been an attractive construct for educational researchers since its conception over twenty-five years ago (Shulman, 1986). PCK received much attention, particularly within science education research, because it presented a new way of conceptualising, acknowledging and viewing a distinct and specialised form of teachers' knowledge. PCK brought together the idea that, as part of their professional knowledge of practice, the teacher linked content knowledge together with knowledge of pedagogy in sophisticated and complex ways which meaningfully enhanced student learning (Loughran, Berry, & Mulhall, 2006).

While the academic world has engaged in ongoing and largely theoretical discussion about that which encompasses PCK (Kind, 2009), it is difficult to find accounts of its value and use for teachers in practice. Abell (2007) called that more PCK research on teachers in practice was needed: "It would benefit the research if conceptual frameworks were made explicit. ... More studies need to focus on the essence of PCK – how teachers transform SMK [subject-matter knowledge] of specific science topics into viable instruction ..." (p. 1134). Specifically, within the realm of science education, Van Driel (2008) called for effective ways of developing science teachers' PCK, particularly because "science teachers often have problems to transform their content knowledge into a form which is appropriate for the specific target group they teach" (p. 1).

In responding to these calls, science education researchers Loughran, Berry and Mulhall (2006) developed CoRes as one such framework. CoRes were intended to engage teachers actively in the process of learning about their own practice, and in drawing out their tacit practices and expert teacher knowledge in ways that would begin to articulate and portray instances of their individual and unique PCK. Importantly, CoRes deliberately attempted to capture the complex knowledge of the teachers' thinking and reasoning behind and about the content of a

specific science content area and the choice of pedagogical activities that would be best suited for their particular students.

In this way, CoRes seemingly offered a way of conceptualising PCK into a usable construct into the real world of teacher practice, and therefore offered a new way of viewing the theory-practice gap (Korthagen & Kessels, 1999; Pekarek, Krockover, & Shepardson, 1996). It is hoped then, that as practicing science teachers' use CoRes in their practice, that the theoretical construct of PCK becomes a more explicit, substantive and valued part of their professional knowledge and provides them with a common language in which they can easily share their PCK with colleagues (A. Bertram & Loughran, 2011).

This research study therefore tested CoRes with practicing science teachers ( $n = 6$ ). The main purpose of the research was to explore these teachers' views on using CoRes in their practice. The two year study explored:

- how CoRes might be *valued* by these teachers;
- how the process of creating one and using it in their practice might, if at all, have influenced or developed their professional knowledge of practice;
- if they felt it captured or portrayed instances of their PCK; and finally,
- how their individual understanding of PCK might have developed as a consequence.

## RATIONALE

In the science education research literature, CoRes have been favourably reported on as an effective instrument in capturing and providing reified examples of science teachers' PCK (Kind, 2009). Yet few studies exist where they have been tested and validated with practicing teachers. This study takes the important step of "testing for applicability" in the classroom and seeks to validate or test CoRes with practising science teachers over a two year period.

## METHOD

This research involved six practising teachers in a longitudinal, ethnographic study (cf. A. R. Bertram, 2010). At the start of the study, the teachers were individually interviewed and asked to describe their current views on teaching and learning. The construct of PCK was then explained to the participants and they were introduced to the framework of CoRes. Participants were then expected to develop and produce their own CoRe based on a science unit or topic that they would soon be teaching. Soon after this stage, the participants were interviewed for comment on the process of making it and how this process might, if at all, have influenced their thinking about teaching and learning, and in particular, how it might begin to reveal and/or develop aspects of their own PCK.

In due course, participants taught the topic or content on which their CoRe had been based. Again, participants were interviewed to explore their views on the impact, if any, that the CoRe might have had in the teaching of the topic. About a year later after using the CoRe in their practice, participants were interviewed to provide their post-intervention views on teaching and learning. These views were contrasted with their pre-intervention views and participants were asked to consider if any changes might have been influenced by using the CoRe in their practice. This final interview also considered the participants' views on the long-term impact or influence which CoRes might have had on their professional practice, and in particular, how they might have, if at all, developed their own PCK.



The major source of data collection for this study came from individual interviews at each stage of the research. The open interview format allowed teachers to offer narrative accounts which enriched the data and provided great insights into their thinking (cf. Clandinin & Connelly, 2000; Conle, 2003). However, a weakness of the reliability and validity of this methodology might be that much of the data relies on self-report. Therefore some degree of triangulation was embedded into the research design to limit these weaknesses and to provide credibility. The teachers' CoRe itself became a data source which was used to reinforce the reliability of the teachers' narrative accounts and the extensive and longitudinal nature of the interviewing process supported the consistency of the teachers' ideas and views over the length of the study.

## RESULTS

All participating science teachers claimed and endorsed CoRes as being an effective instrument which helped them to better understand their professional knowledge of practice. On a general level, all participants believed that CoRes offered them a structured and meaningful means of reflection which forced them to reflect in a purposeful and deliberate manner. Individually though, the CoRe each brought out something different about the practice of each participant. For three of the participants, they felt that it made them rethink their general understanding of what "teaching" and "learning" meant to them on a personal level. For three other participants, they claimed that the CoRe impacted the way they understood the term "student learning" and it caused them to think more carefully of how their particular students' understood the content being taught.

All participants (none of which had an understanding of PCK prior to this study) agreed that the construct of PCK, *as developed through their CoRe*, offered teachers' an important and useful construct for shaping their professional knowledge. For the participants themselves, they now had an instrument which had provided concrete forms of instances of their own PCK. All participants believed that by having an awareness of these instances, and in the process of making the CoRe - the deliberate questioning and reasoning about the content and the pedagogy forced by the CoRe's prompts - improved their understanding of teaching and learning and impacted their long-term knowledge of practice.

The researcher also noticed that the teachers, at the post-intervention stage, now had begun to develop a shared language of communicating their PCK and ideas about teaching and learning with others.

While the participating science teachers' views of CoRes support that it is indeed an effective instrument in articulating and developing PCK and that it would be extremely useful for the professional teacher, there was a major limitation to its design. All participants stated that an enormous investment of time was required for its production; and not one of the participants could see themselves using it in their own practice of their own volition. Two participants suggested that perhaps, CoRes be embedded into the curriculum practices of the school.

## CONCLUSION AND IMPLICATIONS

This research study provides some evidence that CoRes provoked participants to think beyond their normal approach to practice. It also gave them a vehicle from which they could reframe their views in line with a (developing) PCK perspective. In essence, all participating science teachers' claimed that CoRes positively influenced their professional knowledge of practice and enhanced their understanding of PCK. Hopefully, this study has verified to some degree that CoRes offer a valid means for which the academic concept of PCK may be

actualised in practice, thereby reducing the theory-practice gap and presenting exciting new possibilities for research into the important area of that which constitutes practicing science teachers' professional knowledge of practice.

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# **DIAGNOSTIC COMPETENCIES OF PRE-SERVICE TEACHERS ANALYSED BY MEANS OF THE SIMULATED SCIENCE CLASSROOM**

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*Abstract:* Pedagogical diagnostic competence (PDC) is one of the main professional skills of teachers. It is a fundamental precondition to identify students' difficulties in learning or their shortcomings in knowledge, which is fundamentally important precondition though a teacher will be able to select appropriate feedback and actions to support the students' learning. Beyond that, the teachers' PDC is the requirement necessary for the fair judgement of students' performances. However, it seems to be difficult to ascertain PDC in the context of teaching, because in authentic teaching situations the influence of confounding variables can hardly be controlled. By employing a specifically adapted computer program – the “Simulated Science Classroom (SSC)” – it is possible to create teaching-analogue situations in which parameters of achievement and motivation of “simulated students” can be controlled systematically. In experimental studies we investigated specific components of “science related pedagogical diagnostic competence (SPDC)” of 80 pre-service chemistry teachers taking over the role of a chemistry teacher interacting with 12 simulated students. The analyses show that the examinees were able to compose an approximately correct ranking of the simulated students' achievements, but the levels as well as the standard deviations of the simulated students' achievements were systematically underestimated by the examinees (in all of the four different experimental treatments we investigated).

*Keywords:* Diagnostic achievement competencies of (pre-service) teachers, Simulated Science Classroom, Science Learning Achievement, Performance Assessment

## **INTRODUCTION: BACKGROUND, FRAMEWORK, AND PURPOSE**

It is considered extremely difficult to systematically conduct research on diagnosing competency in an educational context, since the number of distracting variables in authentic classroom situations are almost impossible to control. Using a specially developed computer programme, it is possible to simulate classroom-like situations and to systematically control the performance parameters of simulated students. In this way, the classroom situations – albeit that they are simulated – allow for the possibility of using experimental studies to conduct research on pedagogic-diagnostic competencies of (pre-service) teachers regarding their ability to assess the performance of (their) students. – Together with the taskforce “Psychology for Pedagogues” at the University of Kiel, a research group in Freie Universität Berlin's Department of Chemistry Education has developed a set of virtual scenarios which simulate classroom situations in science lessons of grades 5/6.

This article will introduce the development of the computer programme used to simulate these science lessons as well as the first results of our experimental studies with 80 pre-service chemistry teacher students.

## RATIONAL – CURRENT RESEARCH

Aside from being able to show the necessary leadership qualities in the classroom as well as pedagogical skills and knowledge of the subject, a teacher's diagnostic competency plays a significant part in the development and success of lessons (Helmke, Hosenfeld & Schrader, 2004). Diagnostic competency is, in essence, the ability to fairly judge a student's performance (Schrader, 2006). However, diagnostic competency can also include the ability and knowledge to enable teachers to appropriately make these judgments – amongst others methodical knowledge (e.g. knowledge and command of diagnostic methods, knowledge of judgment errors and tendencies) and subject-specific knowledge (e.g. the expectations in a specific area of learning or the difficulties of certain tasks). On top of that particular awareness plays a significant role (e.g. awareness of particular students and classes, e.g. their strengths and weaknesses and the difficulty and popularity of particular subject areas in these classes).

Previous research on teachers' diagnostic competency has focused primarily on the accuracy of diagnostic assessments of written tests. Studies compared teachers' assessments as regards different student traits with the "actual traits" – surveyed using standardised tests. The interpretation of the data is usually restricted to a measure of congruence – correlating calculations between teacher assessment and trait manifestation. According to Helmke and Schrader (1987), three components must be considered when analysing the accuracy of teachers' assessments:

- the *level*,
- the *differentiating* and
- the *rank component*.

The *level component* is a measure of the assessment of the absolute level of a student trait. The *differentiating component* shows whether dispersion of the student trait has been overestimated or underestimated. Finally, the rank component determines whether within a particular class the teacher has correctly determined a rank of the students' performances.

Until now, only few studies on the diagnostic competency of teachers considered all three of these components of diagnostic assessment. If the level of a student's performance is taken into consideration when investigating the accuracy of performance assessments then the results often show an overestimation of student performance (Artelt, Stanat, Schneider & Schiefele, 2001; Bates & Nettelbeck, 2001; Madelaine & Wheldall, 2005). On the other hand, there is usually an underassessment of the dispersion of student performance (Helmke et al., 2004; Helmke & Schrader, 1987), while the rank component is reported as satisfactory (Demaray & Elliot, 1998; Egan & Archer, 1985; Feinberg & Shapiro, 2003; Hoge & Butcher, 1984).

According to this, teachers assess the rank of student performances relatively well. But, all the aforementioned studies focused on the analysis of test subjects' diagnostic qualifications, as determined by written data of student performance (e.g. written tests or examinations).

However, *how is the diagnostic competency of the (budding) teachers affected when the assessment of student performance is solely based on their oral participation in class as this is the case in most school learning situations?*

Scientifically, this question has proven difficult to answer.

## METHODS

### The Simulated Classroom (SCR)

The paradigm of the simulated classroom is a method well suited to experimentally investigate diagnostic competency (Fiedler, Freytag & Unkelbach, 2007; Fiedler, Walther, Freytag & Plessner, 2002). The method comprises a computer simulation of a classroom, in which the user (examinee) takes on the role of teacher and proceeds to interact with virtual students (see picture 1; no. 1); leading to the assessment of experimentally steered student performance, for example.



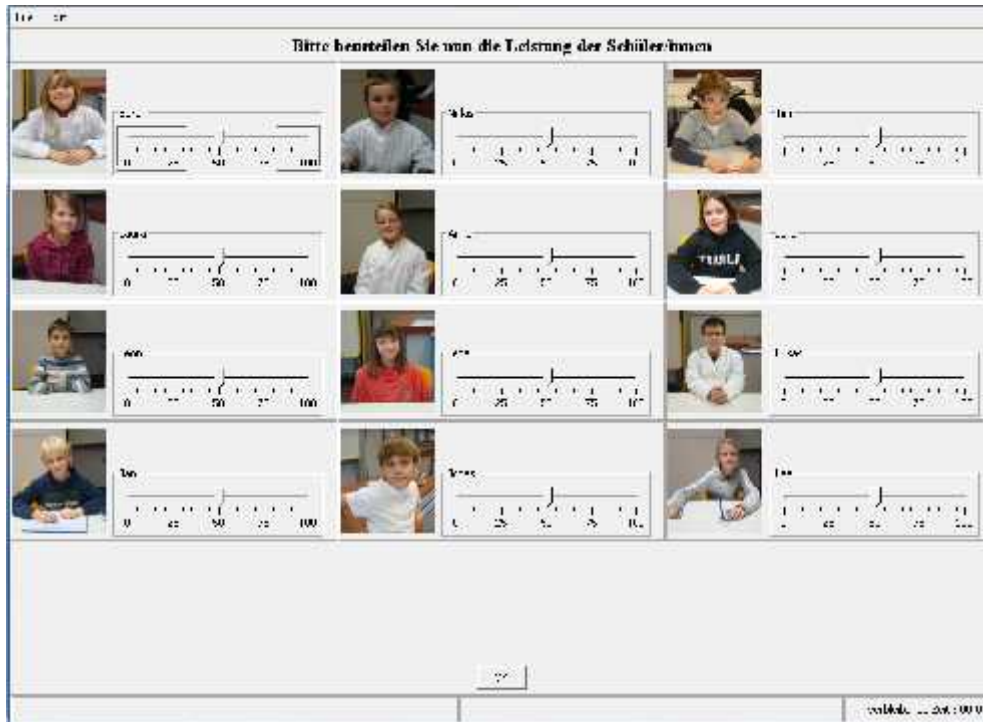
**Picture 1. Screen of the simulated (science) classroom**

During the Simulated Classroom settings the examinee chooses subject specific test questions (see picture 1; no. 2) from a list of topics and contents (see picture 1; no. 3) and directs them at the simulated students (see picture 1; no. 1). The selected question appears on the screen (see picture 1; no. 4). Now, some of the simulated students (pictures) appear in a yellow frame symbolizing that these students show up to give an answer (see picture 1; no. 5) to the selected question (see picture 1; no. 4). These yellowed framed simulated students can be asked by the examinee to give the answer. The student answer then appears and is to read in the “answer-frame” on the screen (see picture 1; no. 6). This answer will be a correct or an incorrect one which is to recognize by the examinee reading and assessing the student answer (and/or by looking on the picture background of the answer which is green in the case of a correct student answer or red in the case of an incorrect respond).

This procedure can be repeated and is to repeat till the simulated lesson is over; in our study a simulated lesson takes 18 minutes. Last but not last, the examinee can see the remaining lesson time of the simulated lesson by means of the “time-frame” (see picture 1; no. 7).

After the simulated lesson the examinee has to assess the performance of each student, first on a scale from 0 to 100 and last but not least by a six-point-rating-scale.

The number of correct answers by the individual simulated student represents his/her performance ability. The performance parameters of the simulated students are selected and fixed by the examiner before the testing of the examinees and – of course before – the investigation of their ability to assess the simulated students' performance.



**Picture 2: Screen of the students performance assessment in the simulated (science) classroom**

The correlation between the students' performance and their assessments by the examinees can be interpreted as the diagnostic competency of the examinee-sample.

The simulated classroom can act as a tool for the experimental investigation of different questions with regard to teacher, student and classroom research. Apart from the students' performance abilities, a wide range of other student traits (such as motivation skills, social interaction, socio-cultural background) can be simulated and investigated regarding their effects in teachers' assessment processes. This is particularly interesting when looking to conduct research on different and specific diagnostic competencies. Nevertheless, the overall aim should be to portray the classroom situation as socio-ecologically valid as possible, while at the same time allowing the investigation of experimentally exaggerated questions with high internal validity.

## The Simulated Science Classroom for Years 5/6

In the course of adapting the programme to incorporate science educational research, the working group agreed on first concentrating on science classes grades 5 and 6 (in German: Naturwissenschaften 5/6). The questions and the anticipated right and wrong student answers, which were developed as part of this project, have been taken from other empirically tested

instruments. By means of these instruments students' conceptions and misconceptions concerning specific science concepts (e.g. the particle model of matter or concepts of inquiry) were analysed (Benedict & Bolte, 2008; Erb & Bolte, 2009). The analysed student answers build the basis for the stimulated student answers in the simulate science classroom (see picture 1).

The research question of this – as far as we know – first science educationally weighted study is:

*In how far are (budding) chemistry teachers able to assess and judge student performance in the lesson correctly?*

The simulated classroom of science classes in grades 5/6 was designed and realized in two different versions. In this publication we will focus only on introducing the results of the version that ignores the influence of the subject content knowledge of the examinee. This concentration on only one treatment version has been chosen for better comparability with the setup of the previous studies we are referencing at (Spinath, 2005; Südkamp & Möller, 2009; Südkamp, Pohlmann & Möller, 2008).

Furthermore, aside from the three assessment components mentioned above (see level, differentiating and rank component) a fourth component, the global degree of variation component – developed and introduced by Südkamp (2010) – will be included in our analysis.

Two questions (which are more methodological in nature) form the core of our experimental study:

1. Are there statistically significant differences in test subject performance (here: chemistry teacher students) in terms of the four selected assessment components between the examinees in this study and those examinees of other studies which were conducted with the help of the simulated classroom? (effect of the subject and the students PCK pedagogical content knowledge)
2. What are the differences in the examinee' diagnostic performance between test run 1 and 2, if they are asked to complete two test runs with the help of the simulated classroom for science in grades 5/6? (training effect)

## RESULTS

### First Investigations Using the Simulated Classroom

In first investigations using the simulated classroom (SCR) conducted by the working group of the taskforce "Psychology for Pedagogues" at the University of Kiel, Südkamp and Möller (2009; see also Südkamp, Pohlmann & Möller, 2008) were able to show evidence regarding the instrument's validity (Südkamp, 2010). Furthermore, the teacher students they investigated by means of the SCR were able to form a rank of student performance within a class. However, the absolute level was overestimated by the Kiel examinee, while the dispersion was underestimated by them.

### Results from the Study using the Simulated Classroom of Science in Grades 5/6

In the research context of science education a sample size of 20 chemistry teacher students was used for the first test run. The results regarding question 1 and 2 are listed in Table 1.

	<b>Bolte et al. (2010)</b>	<b>Spinath (2005)</b>	<b>Südkamp et al. (2008)</b>	<b>Südkamp &amp; Möller (2009)</b>
<b>Rank component</b>	0,40; 0,26	Median: 0,40	0,62; 0,68 0,54; 0,53	0,64; 0,66
<b>Level component</b>	-0,07; -0,09	0,03	0,04; 0,03 0,09; 0,07	0,07; 0,09
<b>Differentiating-component</b>	0,79; 0,71	0,84	0,76; 0,92 0,74; 0,81	0,81; 0,82
<b>Global degree of variation</b>	0,17; 0,19	./.	0,20; 0,15 0,21; 0,20	0,20; 0,19

**Table 1. Results of the analysis of diagnostic competency – differentiated by assessment component and (reference) study**

## CONCLUSIONS AND IMPLICATIONS

In our opinion, the results obtained with the help of the simulated science classroom grades 5/6 are comparable to the results obtained in the reference studies. Noteworthy is the fact that with regard to the results of the rank component, the examinees of the science educational study do not quite reach the level of the examinees in the reference studies. Striking is the drop in performance of the chemistry teacher students (examinees) in the second test run. Interesting and worth mentioning is also the finding that the examinees of the science educational study underestimate the performance level of the simulated students – to our knowledge this effect has not been shown in other studies before.

Further investigations conducted by Bolte, Köppen, Möller and Südkamp should and will show whether these peculiarities and potential discrepancies are a coincidence or whether they have systematic causes (Bolte, Köppen, Möller and Südkamp, in process).

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## DIFFERENT MODELS AND METHODS TO MEASURE TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE

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*Abstract:* This Proceeding will explore the theoretical underpinnings of the construct of PCK as researchers are currently using it. Five speakers will provide perspectives on the overall problem; the theoretical conceptions, measurements, and results used within specific research groups; and provide a synthesis of the research while engaging the audience in discussion.

To consolidate different point of views on PCK, we have selected researchers who use more qualitative methods such as interviews and open-ended questionnaires as well as researchers using more quantitative methods, such as open-ended and multiple-choice items for large-scale paper-and-pencil-tests. This symposium will also be interdisciplinary, connecting biology, chemistry, and physics PCK research, thus shining a rare spotlight on PCK in the natural sciences.

*Keywords:* Pedagogical Content Knowledge, qualitative methods, quantitative methods, natural sciences

## DEVELOPMENT OF THE CONSTRUCT PEDAGOGICAL CONTENT KNOWLEDGE

### Background

Teachers' professional knowledge may be considered the single most important characteristic in instruction. Elbaz (1983, p.11) points out that "the single factor which seems to have the greatest power to carry forward our understanding of the teacher's role is the phenomenon of teachers' knowledge." To categorize this knowledge, Shulman (1987) distinguished seven categories: content knowledge; curricular knowledge; pedagogical content knowledge; general pedagogical knowledge; knowledge of learners and their characteristics; knowledge of educational contexts; and knowledge of educational ends, purposes and values. Ever since Shulman established these categories, many researchers have come to believe that pedagogical content knowledge (PCK) is an important topic in science education, and that high levels of PCK will predict high levels of student achievement (Abell, 2007). However, research has not yet produced a general consistent model or measuring method of PCK (cf., Park & Oliver, 2008; Fischer, Borowski, & Tepner, in press).

In recent research there are two different approaches to model PCK. Some researchers see PCK as was introduced by Shulman: an integrative knowledge category (Gess-Newsome, 1999). This view of PCK includes an 'amalgamation' of other knowledge categories (e.g., content knowledge and general pedagogical knowledge [Shulman, 1987]) with a particular inner knowledge part.

Using this definition of a PCK model, Baumert et al. (2010) showed a high correlation between PCK and content knowledge, even though content knowledge and PCK are separate categories that can be empirically distinguished.

From another point of view, PCK can be seen as a separate category of knowledge with its own unique identifiers (cf., Magnusson, Krajeik, & Borko, 1999). These models are called transformative models of PCK (Gess-Newsome, 1999), because in these models, PCK can be seen as a transformation of knowledge from other knowledge categories (e.g. knowledge of science curricula, understanding of science, instructional strategies and assessment of scientific literacy [Magnusson et al., 1999]). Both approaches to PCK models agree that the knowledge of representations of subject matter and instructional strategies incorporating these representations, and additionally, the understanding of specific student conceptions and learning difficulties are important facets of PCK (Park & Oliver, 2008).

Numerous methods of measuring teachers' pedagogical content knowledge have been developed since Shulman introduced teachers' pedagogical content knowledge: interviews, paper-and-pencil tests for theoretical knowledge, paper-and-pencil and video vignettes for reflective knowledge, teacher training as an intervention and video observation of real instruction, and, very commonly, a combination of two of these. The research studies using these methods can be divided into two groups: small-scale and large-scale assessments.

In small-scale studies, paper-and-pencil tests and a quantitative analysis of video observations cannot be used because psychometric criteria cannot be achieved. On the other hand, in large-scale studies, intervention and interviews cannot be used because the workload is too much.

At the beginning of PCK research intervention, an observation or intervention and interviews were used to investigate PCK in small-scale studies (cf. Lee & Luft, 2008, van Driel, Verloop, & De Vos, 1998). The aim of these studies was not to measure PCK, but to validate models of PCK (cf. Park & Oliver, 2008). Recently, more quantitative studies have been accomplished based on these small-scale studies. More generalizable results about PCK and the connection to other knowledge categories, as well as the connection to the students' outcomes were and will be produced in these large-scale studies (cf. Baumert et al., 2010). A result of the large-scale studies is, for example, that teachers with a higher PCK score create better lessons, which has a positive effect on the students' content knowledge test results. (Baumert et al., 2010).

So four key divergences in the PCK literature exist:

**Nature of PCK:** What assumptions exist for PCK as an attribute of teachers? Is it an unalterable characteristic or does it changes with experience and/or particular kinds of preparation or professional development?

**Model of PCK:** How is PCK related to the professional knowledge base for teaching? Is it transformative or integrative?

**Measurement of PCK:** Is PCK a knowledge base, an artifact of practice, or both? What are the appropriate levels at which to measure PCK? Should it be examined at the topic level (e.g., mechanics) or the domain level (e.g., physics)?

**Contexts for Studying PCK:** Where should the emphasis of PCK research lie? Should it be studied in terms of the translation of teacher knowledge to practice, or in terms of the relationship between teachers' level of PCK and student outcomes?

The goal of this session is to use these questions to analyze the positions taken by the three research groups while grounded in a broader analysis of the field.

## MEASURING PHYSICS TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE (SOPHIE KIRSCHNER, ANDREAS BOROWSKI, HANS E. FISCHER)

**Nature of PCK:** The aim of the study is to find important components of PCK which have a big impact on the students learning progression and motivation. And after that these components shall be integrated in the education of student teachers. So the assumption of the study is that PCK can increase with **professional development**.

**Model of PCK:** Teachers' professional knowledge, which describes the competence in teaching a given subject, has long been recognized in literature as an essential variable for fruitful teaching (Abell, 2007). In order to analyse professional knowledge, it can be broken down into different categories. Recent research (e.g. Baumert et al., 2010) defines three common categories: pedagogical knowledge (PK), pedagogical content knowledge (PCK) and content knowledge (CK). The categories contain many features of Shulman's original seven categories but are differently arranged (Shulman, 1987). PCK is the dimension that only teachers – here physics teachers – have and need. As PCK characterises teachers, is specific for single domains (cf. Park & Oliver, 2008) and is a great predictor of student achievement (Baumert et al. 2010), this presentation will focus on this knowledge category.

**Measurement of PCK:** In this project, PCK is operationalized as a **knowledge base for teaching** with the help of a three dimensional model. The model covers (1) different knowledge areas, (2) themes and (3) facets.

(1) The knowledge areas are divided into three levels: declarative knowledge, procedural knowledge and conditional knowledge (Paris et al. 1983). The reaction to critical teaching situations can be found in this last area. This was tested with vignettes describing a short situation in a classroom, often in the form of a script. We used some of these for the PCK test, but remain aware of the problem that it is difficult to reliably code the answers and to ascertain that the tested teachers focus on the “right” problem.

(2) The content of the PCK, CK and student tests is mainly related to the topics of **mechanics, electricity**, but also contains **physics in general**. Mechanics is part of the curriculum in all German secondary schools.

(3) We use three facets for the PCK test: experiments, teaching strategies and students' preconceptions. Students' preconceptions are important in physics teaching (Duit & v. Rhöneck, 2006) while experiments play an important role in physics lessons. Concepts are a connection between students' preconceptions and experiments: A teacher has to understand physical concepts to decide how to present a topic in a way students can understand it and to avoid deepening their misconceptions. All three facets can be found in the Magnusson model (Magnusson et al., 1999) as knowledge about areas of student difficulty, representations and activities. According to Park & Oliver (2008), it can be assumed that expertise in these facets is important for successful science teaching.

**Contexts for Studying PCK:** The study is part of a bigger project (Borowski et al., 2010), which investigate the **professional knowledge** of biology, chemistry and physics teachers and its influence on the respective teaching/learning process in class and **the achievement and motivation of students** in science. In the first step the professional knowledge of the teachers is being measured subject related by paper-and-pencils-tests. In the next step teacher knowledge will be measured, their lessons will be videotaped and the science knowledge and motivation of their students will be tested.

## Rationale

The COACTIV Study (Baumert et al., 2010), in which mathematics teachers' knowledge was assessed, shows different PCK values for teachers of different school types. The goal of this study is to validate a model, using a related test instrument that has to show on one hand, similar results for in-service physics teachers with similar teacher education (convergent validation), and on the other hand, differences between physics teachers and other groups (pre-service teacher, non-physics-teachers and physicists) who are expected to obtain lower PCK values (discriminant validation).

## Methods

PCK was operationalized by using the model described in the section called measurement. The PCK test for physics teachers consists of 17 items. Open-ended and multiple-choice questions were used in the test. The answers were evaluated with a coding-handbook.

N=167 physics teachers located in two different federal states of Germany were tested. Their average age was 44 years ( $SD=9.9$ ); 29 % were female. The teachers were from different secondary school types in Germany (Bonsen, Bos & Frey, 2008): 137 of them teach at a Gymnasium (GY), 30 at lower level school tracks (NGY). To validate the test, 21 math teachers were tested. The participants completed the test voluntarily in sessions that lasted 50 minutes for this test. They were guided by a supervisor. The entire PCK test has an acceptable Rasch reliability (.76).

## Results, Conclusions and Implications

Teachers who did not study or teach physics got poor results, which confirm that the test is able to measure knowledge that is not pedagogical knowledge, general knowledge or abstract thinking. Physics GY teachers were shown to have a significantly higher PCK than teachers teaching at lower level school tracks (NGY),  $M_{GY}=66.0$ ,  $SD=15.2$ ,  $M_{NGY}=44.2$ ,  $SD=15.8$ . The significance  $p < .001$  was calculated with a T-test, the effect size is large ( $d = 1.41$ ). Of note here is that teacher requirements at different school types in Germany differ widely: Teachers at Gymnasium spend more time at university, and there are differences in the content in teacher education at university, depending on what kind of teacher they are training to become. The results indicate that we are able to measure knowledge that is based on university studies and can be influenced by teacher training. The differences give a first hint that PCK and CK are linked because GY teachers spend more time on learning physics but not on learning pedagogical content.

A valid topic-specific, large-scale paper-and-pencil model for pedagogical content knowledge has been developed. The test, which operationalized the theory-driven model, shows the expected results, which signalizes in sum that we are in fact measuring PCK.

The connection between teachers' test values, their teaching observed by videotaping and their students' knowledge, interest and motivation will be analyzed next. After this, the facets, knowledge areas and topics which are most important for student achievement can be dissected further. In the future, this test can be used to assess physics teachers' theoretical PCK to obtain more generalizable results. These domains will need to be examined in more detail in further studies, which may lead to changes in teachers' education and training and, at a theoretical level, to more focused models for future studies.

## CONCEPTIONS OF PEDAGOGICAL CONTENT KNOWLEDGE (JANET CARLSON, JULIE GESS-NEWSOME)

**The Nature of PCK:** The ultimate goal of teaching is enhanced student learning. We propose that teachers apply two knowledge bases to teaching. The first knowledge bases are academic in orientation. Teachers gain this knowledge through careful study. The knowledge lends itself to measurement through multiple means, including paper and pencil tests. Of Shulman's (1986) proposed **knowledge bases for teaching**, we selected academic content knowledge, knowledge of general pedagogical strategies and skills, and knowledge of the learner as the most relevant to classroom practice. Pedagogical Content Knowledge (PCK) is second knowledge base for teaching. It differs from the academic knowledge bases in that it is **dynamic**, integrates the other knowledge bases, and must be assessed when planning, enacting, or reflecting on teaching.

**Model of PCK:** PCK is the melding of subject matter expertise with pedagogical strategies and knowledge of the learner to produce high quality classroom practice. PCK is a unique knowledge base held by teachers that allows them to consider the structure and importance of an instructional topic, recognize the features that will make it more or less accessible to students, and justify the selection of teaching practices based on student learning needs (Shulman, 1986). With PCK, neither content knowledge nor generic teaching skills alone are sufficient to be an effective teacher. Our **integrative** definition of PCK includes the sub-components: *Content knowledge* including depth, breadth, and accuracy of content knowledge; connections within and between topics and the nature of science; and fluency with multiple modes of representation or examples of a topic. *Pedagogical knowledge* including a rationale linking teaching strategies to student learning; strategies for eliciting student prior understandings; and strategies to promote student examination of their own thinking; and *Contextual knowledge* including understanding of student variations, such as student prior conceptions, impact instructional decisions

**Measurement of PCK:** The following assumptions on teachers' professional learning guide our work: (1) Teachers knowledge exists on a **continuum** from weak to strong. (2) Teacher knowledge can be strengthened through preservice preparation programs, inservice professional development, and high quality curriculum materials. (3) Teachers with stronger knowledge bases are better able to improve student learning. (4) Teachers' professional knowledge bases are related to each other, classroom practice, and student learning. (5) PCK is **topic specific** and can vary by topic. A teacher may have high PCK for "carrying capacity" and a low PCK for "protein synthesis." As a result, PCK cannot be effectively determined at the level of "biology."

**Contexts for Studying PCK:** In our theory of action, we propose that **interventions**, such as professional development, **influence teacher knowledge** bases. These knowledge bases include academic content knowledge (ACK), general pedagogical knowledge (GenPK), and content-specific PCK. We hypothesize that these knowledge bases are related to each other and influence **teacher practice** to become more inquiry-oriented, resulting in greater **student achievement**.

### Rationale

The goal of this study was to examine the construct of PCK and how PCK changes in teachers as a result of an intensive professional development and the use of highly educative curriculum materials.

## Methods

Our data comes from a study of 40 self-selected high school biology teachers across one state. Participants complete a two-year professional development experience to become familiar with high quality curriculum materials, deepen content knowledge, and expand understanding of effective pedagogy. Over the two years, participants implemented the curriculum, attended five weeks of intensive (40 hours/week) summer professional development, and participated in five days of collaborative lesson study and the examination of student work.

## Results

*PCK varied by topic.* In an analysis of sub-scale MFTB scores at the baseline, percentage correct across the five subscales varied as much as by 61% and as little as 8% ( $X=32.17\%$ ,  $sd=12.77\%$ ). When comparing PCK scores across topics using the highest scores in any one sub-topic, scored for an individual varied by as little as 2% and as high as 54% across topics ( $X=18.42\%$ ,  $sd=11.51\%$ ). Clearly, ACK and PCK scores are topic specific.

The *correlation analysis of teacher variables* suggests that they are generally related to one another with most correlations statistically significant. In particular, ACK is not fully distinct from PCK-CK ( $r = .65$ ,  $p = .004$ ) but appears to be more distinct than any of the other teacher variables because it is significantly correlated *only* with PCK-CK. In addition, despite being discrete in our theoretical model, PCK-CK and PCK-PK are strongly related ( $r = .64$ ,  $p = .004$ ).

*Relationships between Teacher Knowledge* (ACK, GenPK, PCK-CK, and PCK-PK) *and Teacher Practice* were tested using ordinary least-squares multiple regression. Despite being generally correlated, the teacher variables are not correlated strongly enough with one another to constitute a multi-collinearity problem in the multiple regression analysis. Teachers with higher GenPK and PCK-CK scores exhibited more inquiry-based teaching practices (GenPK,  $t=3.75$ ,  $p<.01$ ; PCK-CK,  $t=2.06$ ,  $p=.059$ ). No statistically significant relationships were found between either ACK or PCK-PK and Teacher Practice.

*Student achievement* scores increased significantly from pre-test to post-test for all subscales. We used hierarchical linear modeling (HLM) to *determine the amount of variance in student achievement scores accounted for by teacher knowledge bases and practice* in Years 1 and/or 2. Only teachers' ACK accounted for a significant amount of the variance in student achievement ( $t=2.18$ ,  $p=.054$ ). The relationship between Teacher Practice and Student Achievement was not statistically significant, indicating that Teacher Practice is not a mediator of any of the teacher knowledge bases.

## Discussion, Conclusions, and Implications

Participants made positive and significant gains in all of the knowledge bases across the program. While there was not a relationship of ACK to teaching practice, increased ACK was associated with greater SA. PCK-CK increased from the baseline to later time points in the program and was positively and significantly related to classroom practice but not SA. These results are complicated to interpret when compared to other studies. When ACK is measured through proxies such as courses taken and grade point average, the relationship to SA is less than 1%. Direct measures of ACK have positive and significant relationships to SA (Baumert et al., 2010; Hill et al., 2005), as supported by this study.

In Baumert et al. (2010), ACK was related to PCK-CK, as was the case in our study, and PCK-CK had a positive impact on SA in their study while in ours it did not.

While increases in GenPK and PCK-PK over the project are supported by our data, the impact of this knowledge on practice varies, with a positive and significant impact from GenPK but a non-significant impact from PCK-PK. Neither GenPK, PCK-PK, nor Teaching Practice was significantly related to SA. The results may be explained by the mechanical implementation of the curriculum and school-based variables, including testing, that detracted from the implementation of new inquiry-oriented practices.

When considering PCK, the teachers in our study claimed that all parts were important. While ACK laid the foundation for teaching, growth in PK was perceived to be stronger during the project. Our quantitative data supports growth in all areas, though only GenPK and PCK-CK had a significant impact on teacher practice. While we would have hoped to see a stronger impact of the knowledge of student learning (PCK-PK) on classroom practice, this is an area that teachers' admitted to having limited knowledge of and experience with, and it represented a dramatically new way of thinking about their teaching.

## DEVELOPMENT OF EXPERIENCED SCIENCE TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE (INEKE HENZE, JAN VAN DRIEL)

**Nature of PCK:** While PCK has been a subject of research since the 1980s, and much has been written about its importance as a foundational knowledge base for teaching, little is known about the process of PCK development, especially in experienced teachers and in the context of educational innovation. Up to now, few empirical investigations have been conducted into how different aspects of this knowledge are connected and may **influence each other's growth**.

**Model of PCK:** In the present study, we defined an PCK as teacher knowledge about (a) instructional strategies concerning a specific topic, (b) students' understanding of this topic, (c) ways to assess students' understanding of this topic, and (d) goals and objectives for teaching the specific topic in the curriculum. In this, we largely followed the categorizations of Grossman (1990) and Magnusson et al. (1999, p. 99). Compared with Shulman's original construct (Shulman, 1986), these authors adopted a somewhat broader definition of PCK. Acknowledging that the various components of teachers' PCK may interact in very complex ways, Magnusson et al. (1999) claimed, "Effective teachers need to develop knowledge with respect to all of the aspects of pedagogical content knowledge, and with respect to all of the topics they teach" (p. 115). So the study has a **transformative** view on PCK.

**Measurement of PCK:** This study focused on the relationship between parts of teachers' PCK and their experience in teaching PUSc. So in this view PCK is a **topic specific** knowledge base for teaching that can expand for each topic.

**Contexts for Studying PCK:** The study investigates the **translation** of teacher knowledge to practice. For that we followed nine teachers for a period of three years in their natural settings to see if, and how, their initial PCK developed while they were teaching a new subject. The innovation in this study concerned the introduction of Public Understanding of Science (PUSc.) as a new science subject in secondary education in the Netherlands. Among its other objectives, the new syllabus is intended to make students aware of the ways in which scientific knowledge is produced and developed.



Students should gain a clear understanding of a scientist's activities, for example, designing and using models, developing theories, and carrying out experiments (De Vos & Reiding, 1999).

## **Rationale**

The aim of this study was to investigate the developing PCK of a small number of experienced science teachers in their first few years of teaching the new syllabus on Public Understanding of Science. We aimed to identify the content and structure of their PCK of a specific topic in the PUSc. syllabus, namely, 'Models of the Solar System and the Universe', describing its development in terms of relations between its different components (Magnusson et al., 1999). We did not intend to describe in detail the PCK development of each individual participant, but to identify possible common patterns across the knowledge development of different teachers (Verloop, Van Driel, & Meijer 2001). The following research question was central to the study: How can science teachers' PCK of the specific topic of 'Models of the Solar System and the Universe' in the PUSc. syllabus be typified at a time when they still have little experience of teaching PUSc., and how does this PCK develop when teachers become more experienced in teaching this particular topic?

## **Methods**

The study was conducted among nine PUSc. teachers working at five different schools. The nine teachers responded to a written invitation we sent to ten different schools using the same teaching method. The teachers varied with regard to their backgrounds, years of teaching experience, and original teaching disciplines. Among the participants were three teachers of physics, three teachers of chemistry, and three teachers whose original discipline was biology. Their teaching experience ranged from 9 to 24 years at the start of the study. To become qualified to teach the new science subject, the teachers had taken part in a one-year course, which was conducted nationwide. They were all among the first PUSc. teachers at their schools.

With all teachers, a semi-structured interview was held in three subsequent years, immediately after the teaching of a chapter on the solar system was finished. The interview questions were developed on the basis of the results of a study of the relevant literature on PCK, on the one hand, and models and modelling in science and astronomy education, on the other hand.

## **Results**

As a result of the analysis of the interview data from the first year, we identified two types of teachers' PCK of 'Models of the Solar System and the Universe'. These two types were considered as different starting points for the development of teachers' PCK in subsequent years. Type A of PCK appeared to be focused mainly on model content, while Type B of PCK was focused on model content, model production, and thinking about the nature of models. We compared the answers and reactions of the nine teachers with the characteristics of Type A and Type B, and as a result we considered the PCK of five teachers to be more or less indicative of Type A, while the PCK of the other four teachers was classified as representative of Type B. Type A could be typified as mainly oriented towards the teaching of science as 'a body of established knowledge', while Type B could be typified as more oriented towards the teaching of science as 'experiencing science as a method of generating scientific knowledge' (Hodson, 1992).

From our results, we conclude that in the development of PCK of Type A, some of the elements of PCK (especially knowledge about instructional strategies) become more sophisticated or expanded, however, the interaction between these elements was rather static. With regard to the development of PCK elements of Type B over the years, we conclude that changes in the knowledge about instructional strategies, the knowledge about students' understanding, and the knowledge about assessment were mutually related. Teachers' knowledge about goals and objectives of the learning and teaching of 'Models of the Solar System and the Universe' did not change significantly, that is, not only the visualization and explanation of phenomena were still emphasized in this PCK element, but also how to formulate and test hypotheses, and how to obtain information about phenomena.

## CONVERGENCES AND DIVERGENCES IN THE CONCEPTUALIZATIONS OF PCK

### Current Divergences in the Study of PCK

Frustrated by research findings that revealed weak or inconclusive links of teachers' content knowledge to student achievement, Shulman (1986) proposed a "missing paradigm" in educational research, pedagogical content knowledge. PCK challenged past practices of examining knowledge of subject matter and pedagogy separately. Instead, PCK recognizes the melding of subject matter expertise with pedagogical strategies and knowledge of the learner to produce high-quality classroom practice. PCK is a unique knowledge base held by teachers that allows them to consider the structure and importance of an instructional topic, recognize the features that will make it more or less accessible to students, and justify the selection of teaching practices based on student learning needs. With PCK, neither content knowledge nor generic teaching skills alone are sufficient to be an effective teacher.

**Nature of PCK:** Until very recently most PCK research has been devoted to describing strong instances of the construct using qualitative research methods (Research Group 3). Such studies have focused on the characteristics within and between teachers. As these studies do not directly address the origins of teacher PCK, or assumptions made about those origins, some reviewers of this research may draw the conclusion that PCK is an inherent characteristic that teachers either possess or do not possess. Other research efforts build on the recognition that classroom practice has a major impact on student success, and rely on the assumption that teacher actions result from teacher knowledge and beliefs (Research Groups 1, 2, and 3). From this foundation, additional hypotheses follow: PCK exists on a continuum from weak to strong, PCK can be strengthened, and teachers with strong PCK are better able to improve student learning. There is mounting evidence that PCK exists on a continuum, both across and within teachers, and influences teaching practice. Working from the assumption that depth of content knowledge is a precursor to PCK, early studies examined the differences between teachers. Some examined teaching practice resulting from different teacher preparation programs (Research Group 1). These studies demonstrated that depth of content knowledge resulted in differing teaching practices, providing initial support for the PCK construct. When examining the development of PCK over time, the results are mixed. Early studies show that PCK develops with the experience of teaching a topic multiple times. Research Group 2 and 3, when studying the impact of professional development on PCK, reinforces this work. Examining student work or elucidating misconceptions are particularly effective means of increasing teachers' careful consideration of content and pedagogical knowledge on classroom practice.

**Model of PCK:** Building from earlier work and applied to the field of science, Magnusson, et al. (1999) developed a model of PCK. PCK included orientations to teaching (such as inquiry, didactic, and conceptual change) that shaped and were shaped by knowledge of science curricula, knowledge of student understanding of science, knowledge of instructional strategies, and knowledge of assessment of scientific literacy. This model of teachers' professional knowledge defines PCK as a separate and distinct knowledge base with its own unique identifiers. Gess-Newsome (1999) termed this model transformative, meaning that PCK is the product of the transformation of other unique knowledge bases for the act of teaching. In this perspective, the characteristics of PCK such as teacher orientation to teaching science, knowledge of science curricula, and so forth, are transformed into a new knowledge base defined as PCK. This PCK "inside the box" is dynamic and less prone to sub-categorization. For researchers examining PCK from this framework, PCK can often be defined as almost anything that a teacher knows, believes, or can do when thinking about or engaging in the act of teaching. Research Groups 1 and 2 fall into this category. For other researchers, PCK is the integration of the professional knowledge bases, which can be measured individually and within PCK. In this case, PCK is integrative (Gess-Newsome, 1999). Research Group 2 falls into this category. In this case, academic knowledge of content (measured by multiple-choice tests), general pedagogical practices (such as pacing and classroom management), and the ability to list student misconceptions can be contrasted with that knowledge that exists within PCK. PCK is measured through teacher planning, reflection, and practice, and is compared to the other knowledge bases.

**Measurement of PCK:** The existence of different PCK models has resulted in different tools developed and used to measure teachers' professional knowledge as well as the use of different types of analysis for the data collected. For example, when PCK is considered as transformative, many aspects of PCK can be measured, but they generally culminate in a single PCK measure (Research Group 1 and 3). When PCK is considered as integrative, questions about the relative value of the components of PCK to each other and their relationship to "external" knowledge bases become of interest (Research Group 2). This study was purposeful in identifying attributes of PCK and studying the psychometric properties of the definition. While there is generally a lack of consensus regarding the appropriate level of analysis for PCK, all three Research Groups included in this symposium studied PCK at the topic level. In mathematics, PCK is frequently studied PCK at the domain level - mathematics (Baumert et al., 2010).

**Contexts for Studying PCK:** Some studies on PCK have focused on the relationship between teachers' PCK and their other knowledge bases and practice. Others have targeted the relationship between teachers' PCK and student achievement. Only Research Group 2 took this approach. The relationship between teacher variables of academic content knowledge, pedagogical knowledge, and PCK is similar to the finding of Baumert et al. (2010). Their results differ in that teacher variables other than academic content knowledge were not related to student achievement. Fewer studies address the contention that teachers with strong PCK are more likely to increase student achievement. Research Group 1 addresses this question by examining teachers in different career stages, working from the assumption that more experienced teachers will possess greater levels of PCK, though student achievement results are not included.

## Conclusions and Implications

Research on the nature of teachers' professional knowledge, in general, and PCK, in particular, is a topic of great interest to the science education community. While the past 20 years has generated a wealth of data that has the potential to improve teacher preparation with the goal of increasing student achievement, the variety of definitions and tools for PCK limits our ability to create a strong research base. Conversations across research groups, such as this one, are vital if consensus on the construct is to be reached, or if purposeful variation in the research is to be embraced. This symposium represents an initial attempt to find points of convergence across researchers, and determine fruitful avenues presented by the divergences in research agendas. Our hope is to create stronger synergy in our research definitions, tools, methods, and assumptions so that we might improve teacher knowledge and practice.

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# THE PEDAGOGICAL CONTENT KNOWLEDGE OF SECONDARY SCHOOL PHYSICS TEACHERS ON ELECTRIC FIELDS

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**Abstract:** This study examines the initial characterization of the Pedagogical Content Knowledge (PCK) on electric fields of four Colombian secondary education physics teachers. The results revealed four factors that mediate their personal teaching models: their interpretation of the institutional curriculum; the time available to develop the theme in class; the relationship between physics and mathematics; and the consideration of the most effective strategies for teaching physics.

**Keywords:** Pedagogical content knowledge, secondary school physics teachers, electric field

## THEORETICAL FRAMEWORK

For science teachers, the core of their professional development has to be science education itself, since the content to be taught conditions both the teacher's role and the teaching strategies used (Abell, 2007). According to Shulman (1986), teachers develop a body of knowledge about teaching the content – Pedagogical Content Knowledge (PCK) – which is specific to each subject, is elaborated personally in the course of their teaching practice, distinguishes teaching as a profession, and is a form of reasoning and pedagogical action by means of which they transform the content of the subject into representations that are comprehensible to their students. PCK is knowledge that is constructed with its own particular sources, components, nature, filters, and structure (Morín, 1992). From the range of models that describe PCK, the present study assumes that proposed by Friedrichsen et al. (2009) because of the orientations it provides for science teaching, an element that permeates and influences all four components of PCK: knowledge of the curriculum, of instructional strategies, of the pupils, and of evaluation.

Our focus is the topic of electric fields, since this is recognized to be a concept that pupils find hard to learn and understand (Furio & Guisasola, 1997, 1998, 2001; Llancaqueo, 2003). The prevailing teaching itineraries have favoured teaching strategies that proceed from the simplest phenomenology to the more complex (Colombo de Cudmani & Fontdevilla, 1990), i.e., from electrostatics to electric currents, ignoring the part played by the electric field in this transition. Altering this view will involve a profound revision of the teaching models that physics teachers have built up over the course of their classroom practice, both in their initial teacher education and in their professional career. These changes have to start from the knowledge and reflection on what teachers think and do in teaching this concept, combined with their active participation in a process of metacognitive reflection (Mellado et al., 2006)

## THE RESEARCH PROBLEM

The research question we set ourselves was: *What is the initial PCK of secondary education physics teachers in Colombia on the concept of the electric field?*

## METHODS

The participating teachers were three men and one woman physics graduates, with a mean

age of 26 years, and between 3 and 7 years teaching experience. The ages of their pupils ranged between 17 and 19 years.

The study was organized into three phases – documentation, action, and reflection – in which each teacher was to perform a specific task. Each phase was designed as part of qualitative research from a perspective of hermeneutic phenomenology.

The data collection and analysis procedures were: (i) an open choice questionnaire inquiring into what the teacher believes to be the teaching strategies in physics and the role of planning in the teaching and learning process; (ii) the curricular materials the teachers used; (iii) the planning template proposed by Pro (1998); and (iv) the matrix designed by Loughran, Berry & Mulhall (2004) to represent content (ReCo), to which some modifications were made in the number of questions and the form of selecting the core ideas on teaching electric fields.

## RESULTS

All the teachers reduced the core ideas proposed for teaching electric fields to electric force, charge distribution, geometric representation of the field, and field intensity. However, they each focused on some subset of these ideas on which they proposed most of their activities.

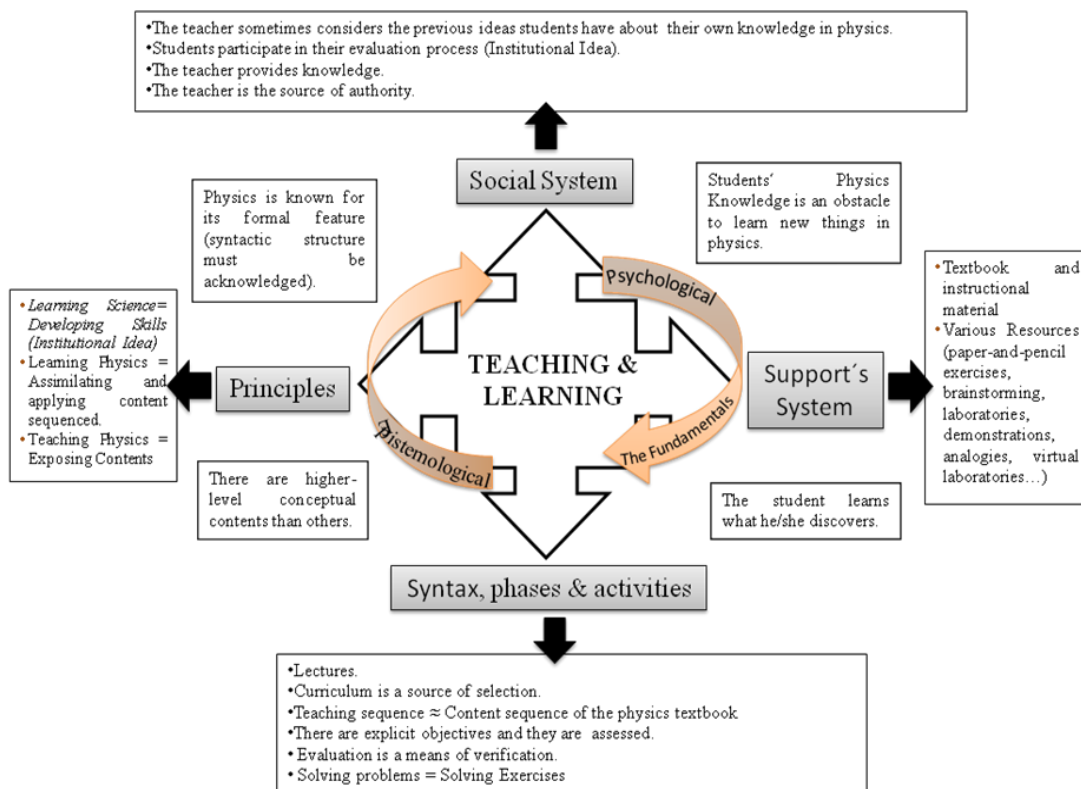
Teacher 1 showed a structure of physics which requires mathematics to be understood. This meant that he emphasized ideas involving the use of algorithms such as the electric force and field intensity, and exercises of application. He also considered that the greatest difficulty the pupils find in understanding the topic is in doing the exercises involving mathematics.

Teachers 2 and 3 focused on the geometrical representation of the field in space, with a view of physics as an interpretation of the world in the form of models. Hence most of the problems or exercises they set had to do with the use and interpretation of lines of force.

Teacher 4 planned his classes around the idea of vector field, as is proposed by the school in which he works. He presents the topic as one more application of this general concept. Although he also presents the idea of physics followed by Teachers 2 and 3, his emphasis in teaching the electric field corresponds more to the idea of physics of Teacher 1. This perhaps reflects this teacher's internal debate between what is required by the institutional curriculum that he has to follow and his own ideas about physics and teaching.

All four teachers centre their teaching on conceptual and procedural content, setting aside in their teaching goals and purposes aspects that are attitudinal or relative to citizenship education. The teachers' stated objectives were both general and specific to the topic. In all cases, these objectives constituted the key criterion mediating the evaluation process, whose character was always as a check of the pupils' learning.

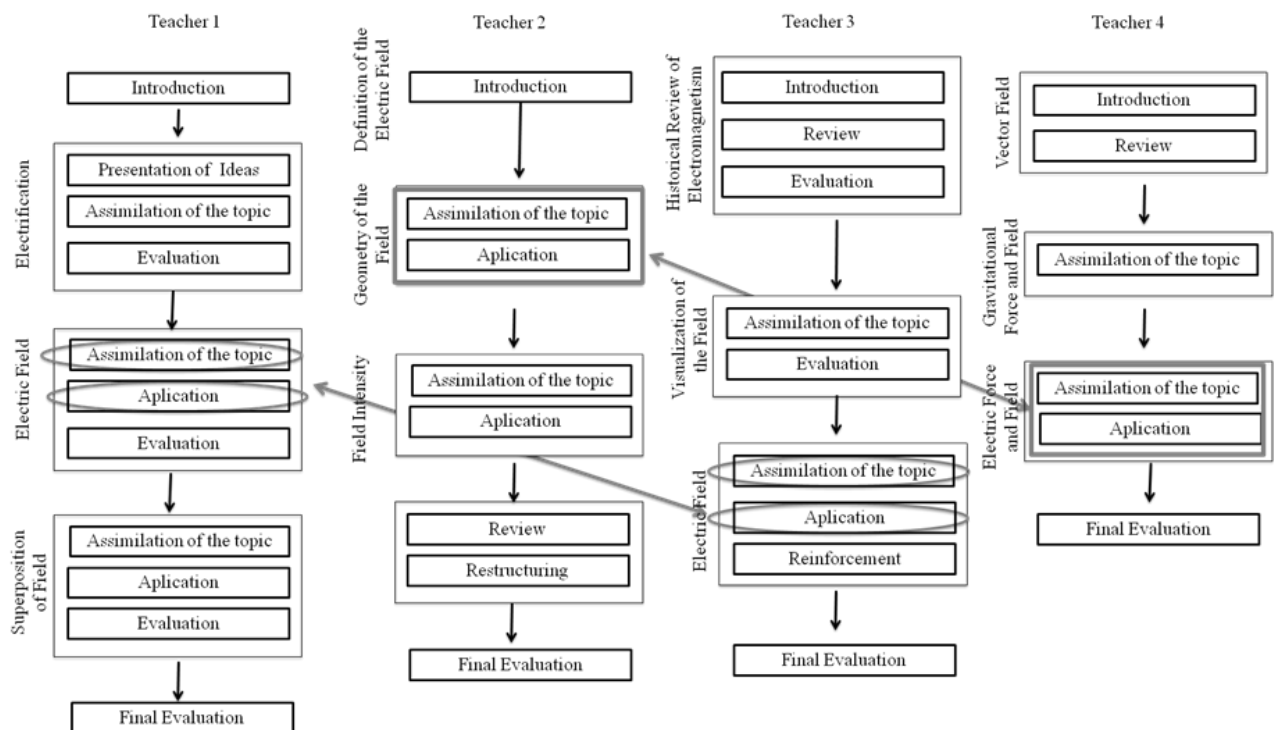
Figure 1: Teacher 1: Teaching and Learning Ideas



The nuances of the traditional model adopted by Teacher 1 (Figure 1) were due to the idea of physics that he fosters together with his role in the classroom. For Teacher 4, it was due to the form in which he implements his school's policies. For Teacher 2, it corresponded to the strong emphasis placed on the time available to work on the topic. For Teacher 3, there was no overriding reason.

The teaching sequences followed by the four participants were extracted from the analysis of instruments (ii) and (iii) (see Methods above). They all proceed by starting with an introduction, followed by a space for the pupils to assimilate and apply the topic, and end with a final evaluation of the unit (Figure 2). The sequences comprise successive blocks which describe how the teacher plans to teach each item of the content linked to understanding the concept of electric field. Teacher 1 repeats microsequences in which the pupil assimilates the subject matter, applies it, and is then evaluated. Teacher 2 prefers blocks in which the pupil only assimilates and applies the topic, leaving the evaluation to the end of the unit. Teachers 3 and 4 use different microsequences for each item of the content. To conceptualize electric fields, all the teachers choose a sequence in which the pupil assimilates and then applies the topic.

Figure 2: Features of the four teacher's instructional sequences



## CONCLUSIONS

There was a general consensus on which content to teach on the concept of electric field. Teachers 1 and 4 keep to the traditional teaching itinerary used in the university education of physics teachers: they proceed from the phenomena of static electrification until they arrive at the concept of electric field, or they define what a vector field is, and then consider the electric field as a mere application of that definition. Teachers 2 and 3 see physics as an interpretation of the world in the form of models, and consider that the pupils need to visualize the field in order to understand the concept, for which reason they change the order of the content to teach.

All the teachers believed the most effective activities in teaching physics to be pencil-and-paper exercises, the teacher's presentation, and laboratory work, regardless of the teaching and learning paradigm the teacher followed.

The factors which condition their personal teaching models are their interpretation of the



institutional curriculum, the time they have available to develop the topic, their ideas on the relationship between physics and mathematics, and their consideration about what is the most effective strategies for teaching physics.

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## **PRELIMINARY STUDY OF TEACHERS' VIEWS ON SCIENCE EDUCATION IN PRIMARY SCHOOL OF SALTA (ARGENTINA)**

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### *Abstract:*

It is presented a progress report with results of a research experience that explores teachers' thinking about factors that improve and those that threaten good science education in elementary schools in Salta (northern Argentina). Data arise from a survey's application and interpretation of a questionnaire assumed as an introductory inquiry designed in a more global Research Project (TRACES). A total of 3500 surveys were distributed and a 14% of them answered it. The present report focuses on the answers to questions 6 and 8 of the questionnaire. Conclusions remark specific responses on the pursued factors.

*Keywords:* teachers' thinking, elementary school, influential factors, educational research-teaching practice gap

## **INTRODUCTION**

The TRACES Project, Transformative Research Activities. Cultural Diversities and Education in Science, funded by the European Commission under the Science in Society action of the 7<sup>th</sup> Program, promotes transformative research activities to investigate the factors that contribute to the research-practice gap, with the aim of proposing guidelines for innovative policies in science education that can contribute to fill that gap. In this Project, desk and field research are being combined in a cyclic process of analysis, action, reflection involving both researchers and teachers.

In particular, we are investigating the effectiveness of research based science teaching (Ratcliffe et al, 2005) facing learners' diversities in terms of individual, cultural, linguistic, gender-related factors.

The first phase of TRACES is a field survey to draw a significant picture of all main actors' perceptions and opinions about the research - practice gap in science education. In each of the partner countries – Italy, Spain, Israel, Argentine, Colombia and Brazil – researchers have developed a 18-item questionnaire applied to teachers of grades 1-10. It focuses on aspects of science education such as availability of resources, interaction among colleagues, pre and in-service training, gender difference, its relationship to research in education. As Ratcliffe et al (2005) say, teachers in science education “recognize and make use of research findings in the course of their normal practice”. In this sense, Jones & Carter (2007) develop a socio-cultural model from which teacher's beliefs about practice is embedded by perceived social norms when implementing an instructional design. Even though, Lederman (1999) states that “results indicate that teacher's conceptions of science do not necessarily influence classroom practice”.

Partially based on these findings, present report is part of the survey developed by researchers from the National University of Salta, carried out in northwestern Argentina.

The objectives for the application of the questionnaires are:

- a) Recognition of opinions to identify parity or difference between those assumed as critical factors in science teaching arising from the inquiry from those so declaimed by the research literature.
- b) Promoting conceptual and strategic hints in relation to public policies and curriculum to take into account in teaching, with the purpose of enhancing science education in primary school.

## METHODOLOGY

It is applied a survey protocol (14 questions) adapted from the original format developed by TRACES Project. Local institutional features are considered and adjustments arise from the pilot test realized before the general application of the final instrument. From the total number of teachers of the province (11.174 teachers), the survey is applied to a sample of 3500 school teachers: from the Capital and inner urban, suburban and rural areas; of unique staff school and plurigrade classes' teachers; from state and private schools; teachers who attend lower, medium and high social class' students, including those coming from native ethnic groups. Responses obtained (478) reach almost 14%. The analysis is made on the answers to questions 6 and 8.

Question 6, *"How positively or negatively influence your teaching each of the following?"*, investigates teacher's opinions on the influence of topics from a didactical/professional, socio-cultural and institutional points of view. Referring to specifically didactic issues it is asked on: textbooks, assessment and learning subsensors. Referring to professional issues it is inquired on training and mastery of content.

Question 8 *"How do you think are the following actions for the purpose of improving teaching and learning science in school?"*, investigates topics seen as contributions of teacher's professional practice. Finally, this question aims to recognize the importance of teaching and oriented curriculum policy in a Latin America context.

Questionnaires were distributed by the Post Office service. However, responses were submitted to the will and commitment of School officers and to the interest of the surveyed teachers. Nevertheless, the number of questionnaires received in the mailbox of the Project was really interesting.

The answers obtained were charged into a computational system specially designed for the purpose of collecting and analysis of data.

Following section tables and graphics demonstrate data analysis emerging from research task and its interpretation.

## RESULTS

Collected 478 questionnaires, a general overview led to realize a general comprehension of its contents. From this early analysis it was possible to find out a set of categories which allowed classifying the given written answers. One of the main categories is related to didactical issues, the other refers to professional development.

The didactical issues point to teacher's beliefs about the sense in which resources such as textbooks, teaching materials, experimental equipments, and so on, are effective when teaching science.

The professional development issues point out various ways in which, in teacher's opinions, science teaching is supported such as pre and in-service training programs, mastery of content, collaborative teacher's assessment.

Referring to first issue teachers believe that educational factors such as textbook, assessment, subsunsors are mainly influential in science education (63.81% - 77.20%), as it is shown in the following tables.

Category: Didactics -  
Subcategory: textbooks

Option	Σ	% Σ
None	12	2,51
Very negatively	1	0,21
Negatively	8	1,67
Without influence	12	2,51
Positively	369	77,20
Very positively	76	15,90

Category: Didactics -  
Subcategory: Form of  
assessment tests

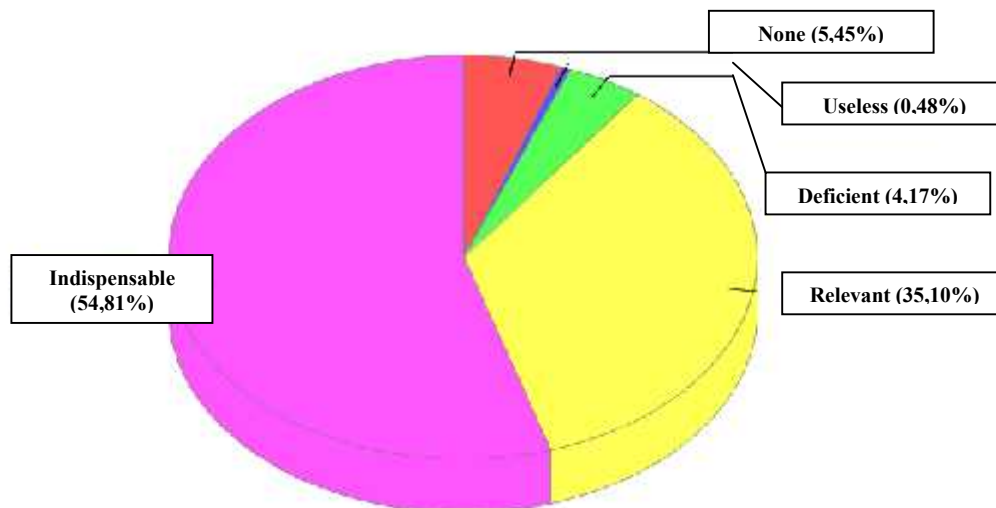
Option	Σ	% Σ
None	53	11,09
Very negatively	3	0,63
Negatively	20	4,18
Without influence	50	10,46
Positively	309	64,64
Very positively	43	9,00

Category: Didactics -  
Subcategory: Subsunsors

Option	Σ	% Σ
None	46	9,62
Very negatively	1	0,21
Negatively	17	3,56
Without influence	23	4,81
Positively	305	63,81
Very positively	86	17,99

As factors related to their professionalism, teachers rate the usefulness of their training contributions (60.88%) and rate very positively the domain of disciplinary content (98.28%).

On the other hand, teachers give importance (86.82%) to the factor *"interaction with colleagues"* when teaching science. The following chart shows:



With regard to teachers' opinion on actions to improve science education (Question 8), they strongly recognize the importance of increasing physical and financial resources (78.03%) and construct special laboratories (69.04%). Thirdly, they ask for secure connections to Internet (55.65%).

Regarding policies to reorient the teaching of science they believe in a percentage lower than 50% in the importance of changing training processes (initial and continuous), reorganizing

the work of teaching and engaging extra-school staff (assistants, bilingual teachers) in educational practice. In terms of public policy a 63.39% think that it should be changed the criteria for teacher selection.

Category: Professional -  
Subcategory: Exchange with  
colleagues on successful or  
not experiences in the  
classroom

Option	$\Sigma$	% $\Sigma$
None	21	4,39
Useless	3	0,63
Deficient	22	4,60
Relevant	170	35,56
Indispensable	262	54,81

Category: Professional -  
Subcategory: Link teaching  
practice/educational  
research

Option	$\Sigma$	% $\Sigma$
None	39	8,16
Useless	7	1,46
Deficient	11	2,30
Relevant	195	40,79
Indispensable	226	47,28

Category: Didactics -  
Subcategory:  
Development of new  
didactical materials

Option	$\Sigma$	% $\Sigma$
None	23	4,81
Useless	7	1,46
Deficient	8	1,67
Relevant	150	31,38
Indispensable	290	60,67

Among the professional factors teachers highlight the importance of sharing with colleagues and of linking their practice with the results of educational research (88.07%).

The study also reveals the need of new materials developing, recognized by 92.05%, and achieving mastery of disciplinary content (98.28%), giving support to a better science teaching.

## CONCLUSIONS

478 elementary school teachers answered a 14-items questionnaire. Questions arise opinions and conceptions about the basis of science teaching: the influence of didactical approaches and of professional background as well as cultural issues, such as socio-cultural and interpersonal relations factors which improve or impede a better science teaching. This survey has TRACES research project as a framework.

Question 6 and 8 are selected because they refer to the inner classroom practice of teachers by considering the practice itself or the pre-service teacher's training or the in-service teacher training, the interaction with colleagues, as well as the importance given to the didactical devices.

It is stressed the importance of ensuring teaching science through content mastery and teaching strategies management. It is remarked the importance of providing didactical materials and financial resources, laboratories, internet connections when teaching sciences. Teachers also give importance to guidelines and evaluation criteria and presence of learning subsensors. As professionals they recognize the convenience of working with colleagues and the contribution of researchers to their professional practice.

These results, from a didactical or a professional point of view, allow the design of successive research phases looking for narrowing the research-practice gap, the principal TRACES objective.

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# **INTEGRATED TEACHING OF SCIENCE AND TECHNOLOGY IN FRANCE: AN EXAMPLE OF A COOPERATIVE TEACHING.**

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*Abstract:* In France, since 2006, an Integrated Teaching of Science and Technology (ITST) has been set up as innovation in middle school. First and foremost its goal is to bring a new unit of teaching in which Science and Technology are not poles apart from different disciplines. The implementation of ITST by teachers usually specialized in one discipline (biology, physics or technology) needs to develop new teaching ways. Within a theoretical framework Didactic of Curriculum and using a methodology based on Content Pedagogical Knowledge (PCK), are mobilized by teachers to implement ITST. This data was collected from two sources : official instructions and video recordings teachers' meeting to prepare lessons or teaching in classroom. The results show the emergence of a new curriculum, and a new approach of teaching but without necessarily devoting oneself to one skill widening from initial discipline teaching.

*Keywords :* curriculum- cooperation – specialist – integrated – school discipline

## **1. INTRODUCTION**

Integrated Teaching Science and Technology (ITST) is promoted to prospect for European and International Education Program. Instance of this, Quebec in 2007 gave up the former scheme in distinct disciplines, so that integrated teaching could be kept on. Australia, Taiwan, Greece have also experimented an integrated teaching. In France, the French Ministry of Education and the National Academy of sciences and technology has been supported ITST as an innovation since 2006. To implement ITST, Inquiry-based Science Education (IBSE) is recommended and two main topics are concerned that is : Energy and Material. Actually, fifty middle schools have taken part in ITST innovation, including pupils for grade 6 (age 12). In France, ITST contrast with the traditional scientific teaching. Usually biology, physics and technology are three main disciplines taught in secondary school. As regards ITST, a teacher specialized in one of these disciplines become a teacher of Science and Technology (Fig 1). ITST is a new teaching and a new professional experience for teachers. To keep up with it, the latter must share their conceptions about integrated teaching and build on a new way of teaching. Drake (2007) explains how teachers must overcome their resistance to elaborate integrated approaches and strategies. They need to cross different approaches (multidisciplinary, interdisciplinary, or transdisciplinary) and different teaching strategies to include thematic subjects, learning projects, IBSE practice in integrated curriculum.

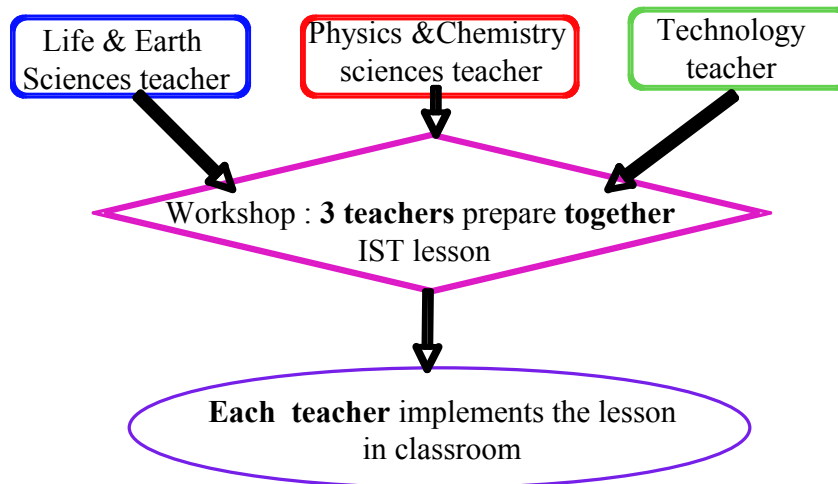


Fig 1. Organization of ITST

This new teaching device have a significant impact on teaching practice and relationship between teachers. For example, to get ready to work out a lesson, three specialized teachers, each one in one discipline, meet once a week to carry out choices and make decision. But, implementation of ISTS is conducted by each teacher in classroom of S& T.

## 2. RATIONALE

Firstly to study the collective construct and the individual practice, we are likely to use the framework proposed by Martinand (2003) going through curricular steps. By curriculum, we are acknowledged upon official instructions, not to mention the references that guide teachers' choices. Our analysis is based on four steps (Fig 2).

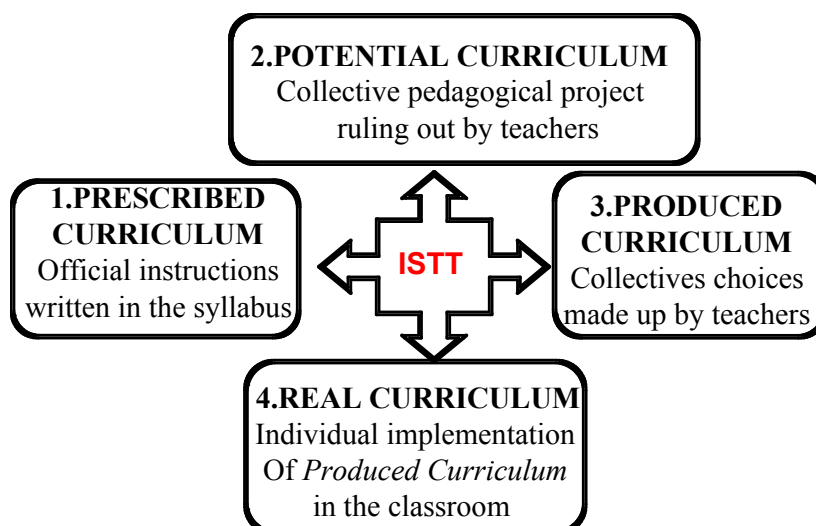


Fig 2. Stages of curriculum development

- *Prescribed curriculum*, i.e. official scientific or technological content for each discipline and also pedagogical activities for pupils;



- *Potential curriculum* is characterized by different teachers's interpretations of the prescribed curriculum;
- *Produced curriculum* is a transcription of the teachers's choices within different interpretations from the prescribed curriculum ;
- *Real curriculum* corresponds to what each teacher really implements in his classroom.

As for each curriculum, the purpose is to identify which knowledge is mobilized by teachers and what difficulties they encounter in implementing ITST.

Our hypothesis is implementation of ITST requires for specialized teachers (biology, physics or technology) to go well beyond the field of their own disciplinary teaching and eventually acquire new professional knowledge. How does a specialized teacher became involved in ITST and jointly worked out the ISTT implement ?

More precisely, we question :

- The relationship between specialized teachers to implement ITST;
- The stand of the teacher either a teacher of « S&T » or a specialized teacher who will bring out his expertise in ITST;
- The role of the IBSE to unify S&T;
- The meaning of the "I" of ITST does it mean integration of discipline, interdisciplinary, unlikeness of school discipline ?

Thus ISTT implementation requires :

- firstly to cross school disciplines
- secondly to acquire a new professional expertise connected with a new way of teaching.

The goal is to determine what pedagogical knowledge are summoned up by 3 teachers to develop and implement ISTT.

### 3. METHOD

We hold on a case study two teams (from two different middle schools) of three teachers, each one specialized in biology, physics or technology.

#### Data collection and corpus

Data collection is provided

- for the *prescribed curriculum*, content of official instructions in ITST and also supplied by two curricula topics namely "Energy" and "Material";
- for the *potential curriculum*, with exchanges and negotiations talk between the three teachers to get ready the lessons in ITST, from transcribed video recordings (10 hours);
- for the *produced curriculum*, with the notebook where team-teachers write down the choices of progression, demonstrations, explanations to help the learners.
- for the *real curriculum*, with the interventions of each of the three teachers in ITST classroom, from transcribed video recordings (10 hours).

#### Analysis of the corpus

To answer our research questions, we try to determine what knowledge is mobilized by teachers according to four curricula above. Analysis of the corpus has been based on *Pedagogical Content of Knowledge* (Shulman, 1987) :

- *Subject Matter Knowledge (SMK)* or content knowledge in academic disciplines,

- *Pedagogical Knowledge (PCK)* or teaching knowledge to transform the content ITST into a powerful pedagogic (illustrations, demonstrations, explanations...),
- *Knowledge of learners (KL)* or misconceptions, taken into account of the learning difficulties to the pupils,
- *Curricula Knowledge (CK)* or content knowledge of the school curricula and the pedagogical equipment available (laboratory material, software...) to implement ITST.

For example during the concertation meeting to elaborate the *potential curriculum*, teachers refer to Energy concept. At first, starting from their own discipline, each of them gives a specific definition, and so, they mobilize SMK from academic discipline. After that, the discussion is concerned with what kind of examples are likely to be chosen to illustrate energy. Teachers of technology and physics propose electric energy while the teacher of biology will propose muscular energy. In this case, each teacher mobilizes “disciplinary PCK”. But sometimes, team-teachers try to combine transversal examples of energy as a common transformation process from a source (sunlight for electric energy or nutrients for muscular activity). In this case, they mobilize a shape of “integrated PCK”.

## 4. RESULTS

The analysis highlights different results.

- As for the *prescribed curriculum*: Content Knowledge of biology and physics and technology are patchwork-stuck. Moreover, a tension between disciplinary curricula and the interdisciplinary topics in ITST results in.

Out of 34 items in the Teacher’s Guide book « Matter and Materials » the graph (Fig 3) shows the distribution between school disciplines. We note down that traditional school disciplines are a minority compared to cross-disciplines.

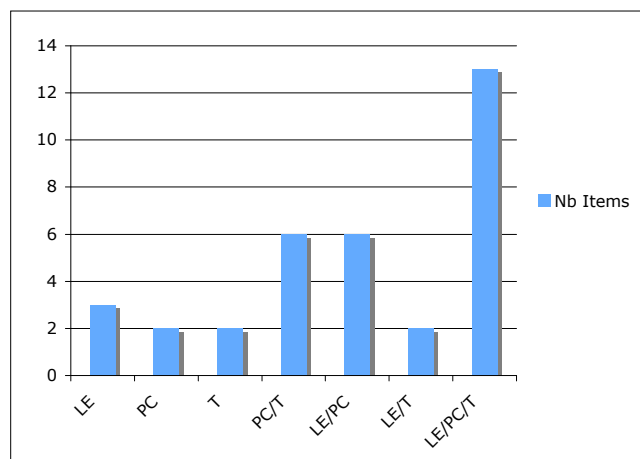


Fig 3 : Distribution items according to school disciplines in the guide book (LE : Life and Earth science, PC : Physic and Chemistry science, T : Technology)

Each school disciplines items mobilize MSK (e.g concepts : matter, energy, cell, technical object ...) and then, when one crosses disciplines items, PK is mobilized.

- As for the *potential curriculum*: collaboration and cooperation between teachers is vividly expected about content knowledge in academic disciplines, about teaching Knowledge to

clear up the pedagogical goals for ITST and decide the many choices to get through with it.

During the discussion between the three teachers, four types of knowledge are mobilized :

- MSK are summoned to try a common definition of energy
- KL to anticipate the difficulties to be overcome and pupils' skills to undertake something...
- PK to plan the lesson.
- CK about laboratory equipment useful for the lesson

The graph (Fig 4) shows that a great deal of time is spent upon the discussing of laboratory equipment and planning lesson (e.g some teachers do not know how to use the laboratory materials : a microscope, a drill, a software, or else and so, they need to be guided with a specialist teacher's eye ).

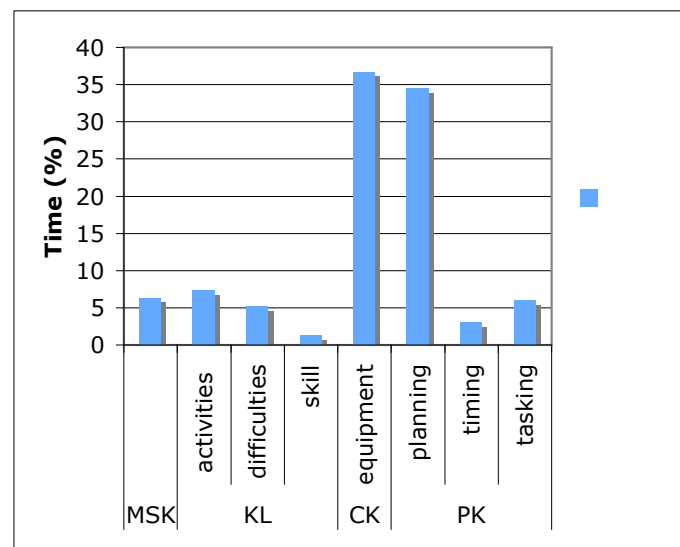


Fig 4. Units of discussion and time spent (%) during a working meeting (92 min)

- As for the *produced curriculum*: plan, organization and activity tasks for learners (Fig 5).

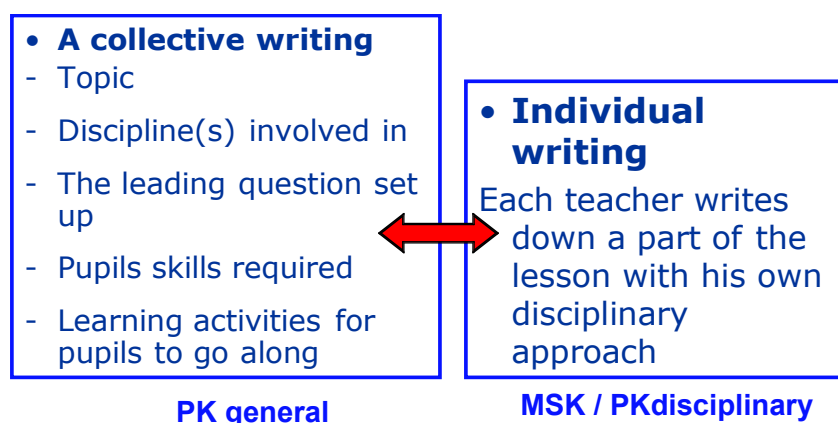


Fig 5. Organization of the working paper for the lesson

On the one hand, PK about the plan of a lesson are summoned up by a teacher team to produce a working paper, in 5 points come to focus : topic/ discipline involved in /, the leading question set up/, pupils' skills required and learning activities for pupils .

On the other hand, each teacher writes down a part of the lesson with his own disciplinary approach (MSK or PK disciplinary).

Concerning the tasks appointed to the learners about specific concept (i.e construct a breeding cycle), team teacher delegates the draft of the learning task to the teacher who is recognized by all, as a specialist (in this case the teacher of Biology is called in). That is, each teacher bring its expert testimony in a discipline to an integrated teaching. So to say, each team of teachers form each school produces a “local” curriculum, that is to say, they don’t exactly choose the same pedagogical goals or activities tasks for learners.

- As for the *real curriculum*, each teacher introduces him(her)self in classroom of « S&T » as a teacher of S&T and not as a teacher in biology, physic nor technology Nevertheless, teachers don’t always master the MSK the learners are due to be taught. Teachers can’t figure out the difficulties or the misconceptions of learners and sometimes are unable to answer their questions. This deficiency is compensated with a friendly talk between teachers. In this case, the teacher explicitly tells the pupils off that he must seek out for a specialist teacher’s help to fill in the gap of the expertise knowledge of the disciplines. He or she mobilize cooperation knowledge.

To describe IBSE, each teacher does reference to the professional practices from academic discipline. Thus, two ways of thinking IBSE arouse either experimental method with scientific practices for teachers in biology and physics, or design method with manufacturing practices for teachers in technology.

## 5. CONCLUSION

In comparison with other studies, in particular the Australian study led by Wallace & al (2007) we have also noted a disparity between Integrated Curriculum prescribed and the real practice in ITST, because Integrated Curriculum practice doesn’t exist. ITST is a new way of teaching without professional memory assess or pedagogical tradition. If group work is recommended, the organization is very disparate according to the schools.

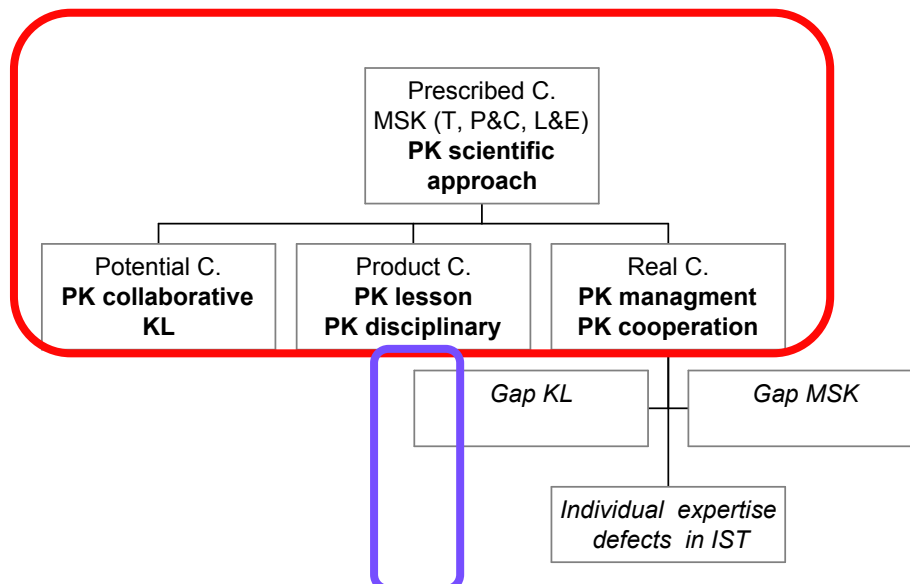


Fig 6. Knowledge mobilized in the developement of local curriculum (Red frame : collaboration and cooperation between the 3 teachers, blue frame : limit of professional enlargement in S&T for each specialized teacher )

In conclusion, each curriculum is characterized by different knowledge and it is difficult for each specialist teacher to go out of the speciality field.

The implementation of ITST in classroom, from a local curriculum collectively produced needs worthwhile collaboration and cooperation between specialist teachers. Still, it appears that there is no professional widening from the speciality.

Anyhow, the collaboration seems to open prospects with new disciplinary interactions. Noting collaboration between teachers from different disciplines constitute here a real newness in the professional development. Meanwhile, there is a paradox. At the moment, ITST innovation in France is more a juxtaposition of disciplines rather than a real integration. But, it also appears that the meaning of “integration” in ITST must be understood like the disappearance of the school disciplines in a new school discipline « S&T ». At all events, this new integrated teaching seems to raise a new speciality teaching claim for an ITST specific curriculum.

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# SEMIOTIC MEDIATION AND DIDACTICAL CYCLE AS METHODOLOGICAL REFERENCE FOR PRIMARY SCHOOL TEACHERS

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*Abstract:* The theoretical framework of semiotic mediation, after a Vygotskian approach within activity theory, fruitfully introduced for mathematics education, has been transposed and adapted to laboratory science education activities. Aim of this paper is to show how this framework can be used as a methodological reference for teachers to mediate scientific meanings. An example addressed to teachers of application to laboratory activities with a jet car toy is proposed.

*Keywords:* Semiotic mediation, Force Dynamic Gestalts, Energy, Didactical cycle, Primary school science education

## DEFINITION OF THE PROBLEM

Primary school teachers have difficulties in teaching sciences and in particular in driving laboratory activities, addressed to meaning construction and modeling, to achieve a lasting effect of science education. Science laboratory activities risk to be reduced to a set of trivial practices, or mere manipulation, or twiddling, to be executed by students, without the suitable and precise teacher's guidance, while, according to the Vygotskian perspective of *obucenie* (Mecacci, 1990), the teacher's active role is fundamental. In literature or in textbooks, a wide variety of educational school courses is documented, while effective methods on teaching /learning processes are not so widely available. In this contribution, after a synthetic presentation of a proposal of a methodological framework, an example of semiotic approach to introduce students' to energy meaning construction will be presented and discussed.

## PLACE IN THE LITERATURE

In mathematics laboratory education exists a well defined and consolidated framework of semiotic mediation (Bartolini & Mariotti, 2008) to guide and foster methodological and educational competencies in teachers. This fits Vygotskian tradition that considers learning a mediated relation between individuals and knowledge. Artifacts and instruments are key terms of Rabardel's theoretical construct that defines an instrument as "a mixed entity made up of both artifact-type components and schematic components that we call *utilization schemes*. This mixed entity is born of both the subject and the object. It is this entity which constitutes the instrument which has a functional value for the subject" (Rabardel & Samurçay, 2001). However Rabardel's approach is not enough to be used in teaching/learning processes in which

Vygotsky's analysis of technical (artifacts) and psychological (sign)<sup>1</sup> tools and Hasan's (2002) investigation of complex semantic relations of mediation processes are necessary. In the learning process, a child needs the help of the teacher to cross the Vygotskian zone of proximal development and to internalize new knowledge.

## SEMIOTIC MEDIATION AND DIDACTICAL CYCLE FOR SCIENCE

The key terms of Bartolini & Mariotti's framework can be reinterpreted to suite the specific case of science. Fig. 1a reports the sketch of the elements and the links of the theoretical framework of semiotic mediation adapted for science.

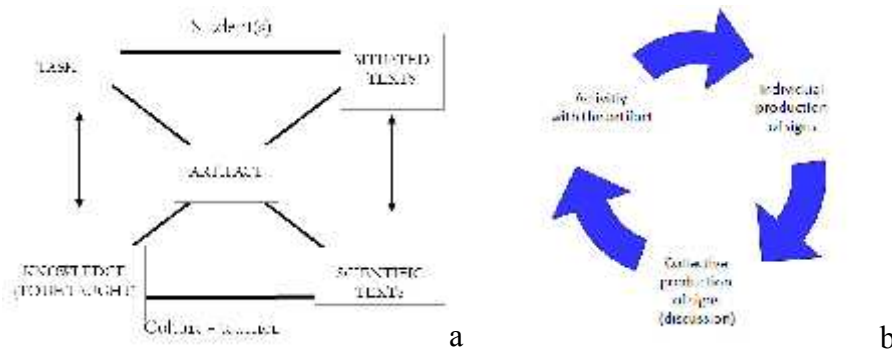


Fig. 1. Elements and links of the (a) theoretical framework of semiotic mediation and (b) the didactical cycle

At the centre of the laboratory work there is an *artifact*. The artifact, may be any scientific “instrument” available in scientific laboratories (easily assimilated to mathematics artifacts and to Rabardel’s *genèse instrumentale*) or the reproduction in the laboratory of a piece of reality, according to the analysis of Knorr-Cetina (1999), with the aim of simplifying and focusing particular aspects. The artifact embodies meanings that students have to discover and internalize, and this is stimulated by the *task*. The task, a question or a problem posed by the teacher, reflects the fundamental steps of a scientific research. The tasks may refer, for example, to the description of the artifact itself and of the function of its parts, or to the prediction of its behavior under certain conditions, the solution of a problematic situation or the way to achieve a certain result, the description of a process or of a phenomenon involving the artifact, its interpretation, the identification of relevant invariables as well as their relations. The teaching-learning process starts with the emergence of students’ personal meanings in relation to the use of the *artefact*. The students, stimulated by the task, construct personal meanings through *utilization schemes* of the artifact, i.e. from simple manipulation and exploration of the artifact, to well designed experiments with choice of the parameters and of the quantities to be varied and measured. The teacher’s role here is again fundamental and well defined. By all these activities children produce some specific personal *signs* (written or oral words, gestures, drawings,...) that the teacher may recognize and interpret as “pivot” signs to be made evolving. “pivot” signs may be used by the teacher to create a link between the plane of concrete experience and the plane of meanings, for the evolution towards *scientific text* and the processes of meaning construction. Their evolution has to be fostered by the teacher through specific social activities. In summary, the process of semiotic mediation consists in the evolution process that has its first step in the emergence of personal meanings related to the accomplishment of a task and develops in the collective construction of shared signs related to both

<sup>1</sup> The sign acts as an instrument of psychological activity in a manner analogous to the role of a tool in practical activity

the use of the *artifact* and the science to be learnt. This evolution is promoted through an iterate cycle (Fig. 1b) that includes (i) activity with the artifact, (ii) individual production of signs, and (iii) collective discussion, pointing at the shift between the *situated texts* produced by the children (Fig. 1a) to forms of *scientific texts* (suitable to students' age) that are decontextualized from the specific situation and, at the same time, able to evoke the concrete experience. Each of these activities contributes differently but complementarily to develop the complex process of semiotic mediation (Bartolini Bussi & Mariotti, 2008). *Activities with the artifact* constitute the start of the cycle. They are based on tasks, as are designed with the aim of promoting the emergence of signs related to artifact use. In some activities students are involved *individually*. For instance, students might be asked in classroom or as homework to write individual reports on the previous activity with the artifact, reflecting on their own experience and raising possible doubts or questions, to find analogous situations to the studied one. Written productions can become objects of discussion in the following *collective classroom discussion*. This third activity plays an essential part in the teaching-learning process and constitute the core of the semiotic process, on which teaching-learning is based. The whole class may be engaged: for instance, after a laboratory activity, the various individual or small group descriptions and interpretations (students' written texts or other texts ) may be analysed, commented and discussed collectively. The main objective of teacher's action in such a discussion is that of fostering the move towards science meanings, taking into account individual contributions and exploiting the semiotic potential coming from the artifact use (for the elaboration of the concept of Mathematical Discussion, see Bartolini Bussi, 1998a, 1998b).

In the different steps of the methodological framework we have here illustrated the teacher's role is different and crucial. It ranges from the choice of suitable tasks, which exploit the semiotic potential of an *artifact*; to the professional recourse to suitable interaction strategies during the tricky step of classroom discussion. The study of the teacher's role is in progress in pilot experimentations with teachers-researchers and in the diffusion of classroom activities with *artifacts* to the broad education system.

## A POSSIBLE TEACHER TRAINING PATH ABOUT ENERGY

In order to apply this methodology, teachers need first to be trained, putting themselves in the same situations (i.e. using the same artifact, answering to similar tasks, producing and discussing pivot signs they expect from students) they could offer to their students, thus to experience possible difficulties and needs of children and to focus science knowledge in relation to children experience urged by the artifact use as *instrument*. In the following, we outline an example of contents of an application of the semiotic mediation framework addressed to teachers with children of the 4<sup>th</sup> and 5<sup>th</sup> grades. We will refer to the elements shown in Fig. 1.

**The piece of knowledge to be taught.** The concept of energy is very hard to be understood by young students. However some basic concepts can be introduced very early to prepare the scientific meaning construction in a vertical curriculum perspective, i.e. the identification and differentiation, teacher guided, of the Force-Dynamic Gestalts (FDG) (Fuchs, 2007). They are the schemas that the mind uses to make sense of experience, by metaphorically projecting them onto concrete phenomena. Various phenomena, such as those involving the behavior of fluids, electricity, heat, motion, and chemicals, treated separately by different fields of science, can be understood in terms of analogous basic and simple structures already present in children's minds (Fuchs & al., 2011).

Metaphoric actors of natural processes are fluid-like quantities (extensive quantities), with associated intensities (generalized potentials or intensive quantities) which differences (potential differences) drive fluxes. The power of a process in an interaction is determined by its quantity and the connected potential difference: a certain increase of potential of a certain



quantity (effect of the interaction) occurs at the expense of a certain decrease of potential of another certain quantity (cause in the interaction). The concept of energy then arises from the identification of the “proportion” between two processes taking part in an interaction.

**The artifact.** We consider a jet-car toy (Fig. 2).



Fig. 2: The jet-car artifact.

Other artifacts can be, for example, a putt-putt boat, a windmill, a dynamo torch, or, with reference to natural sciences, a tree, an ecosystem, the blood circulation, the water cycle, chemical reactions etc.

**The task.** The task invites observing and investigating how a device (a toy) functions; the relationships between its parts; how the problematic situations posed by the task may be solved; the prediction of the behavior of the apparatus under certain initial conditions; the interpretation of the observations (Mariani & al., 2011). With reference to the jet-car, the tasks can be grouped as: (A) exploration of the toy as an artifact (Describe the jet-car. Describe and draw by which parts is it composed); (B) exploration of the experimental apparatus as a tool (How could you use it? How could you make the car go faster? Or go further?); (C) use of the toy with utilization schemes (After the experiments: What did you do with the jet-car? What did the car do? How do you explain your observation? Perform several experiments with the inflated balloon to move the toy car by changing the air in the balloon and the mass of the car. Make changes one at a time); (D) search for relationships, detailed analysis of the toy (balloon inflated and exhaust hole kept closed: What quality has the air in the balloon? What does the air “feel”? What quality has the jet-car?; exhaust hole open: What quality has the air while it is coming out of the hole? What does it “feel”? What quality has the air after it is come out of the hole? What does it “feel”? What quality has the jet-car while the air is coming out from the hole? What does it “feel”? What quality has the jet-car after all the air has come out of the hole? What does it “feel”?). Each task generates a didactical cycle.

**The evolution of situated texts towards scientific texts.** In a real case, for every task, children produce sentences, words, expressions, drawings, sounds, gestures that the teacher may recognize as “pivot” signs. For example, during a collective discussion, pivot signs could be: “air is trapped”, “a wind exits the hole”, “air mixes with outer air”, “the car moves forwards while the air is blown out”, “the car gradually stops”, “more air-more speed”, “all is resting”,... Teachers, once invited to hypnotize possible students’ situated texts, have to be trained to conduct collective discussions for gradual construction of scientific meanings starting from the pivot-signs. The steps in the case of energy could be: i) description of the process as a whole using common language; ii) refinement of the language used, stressing quantities that play a role; iii) description of the process in terms of fluid-like quantities, associated differences of potential and elementary concepts (current, resistance, capacitance, etc.); iv) interpretation in terms of cause-effect (so far the word “energy” is still not used); v) introduction of energy as proportion between causes and effects.

A possible scientific text that teachers should make is the following. *When the balloon deflates, the car accelerates, reaches maximum speed and gradually goes to rest. The air expelled backward pushes the car forward. The car moves but, at the same time, loses motion. After the balloon is completely deflated, the car loses all its remaining motion and stops. A more formal text could be the following. The air expands due to the pressure difference and exits at high speed from the car nozzle. Thus momentum is transferred to the car proceeding in the opposite direction. The car accumulates momentum and, at the same time, transfers part of it to the earth as a consequence of the velocity difference. When all air has been expelled, the car momentum gradually flows to the earth until the velocity difference becomes zero. The air pressure causes the transfer of momentum from the air to the car, air interacts with the atmosphere and car interacts with earth causing production of heat. The energy contained in the compressed air is transferred to momentum (a greater fraction to the air than to the car) and from momentum to heat.*

## CONCLUSIONS

We have proposed a methodological framework of semiotic mediation and the didactical cycle worth introducing to teachers as reference for scientific meanings construction in laboratory activities.

The various elements and links have been discussed and exemplified for the case of energy meaning construction. This work shows the feasibility to anchor scientific meaning construction to children's reasoning, starting from the image schemas of the FDG, suggesting a methodology that makes the teacher confident in the use of natural language.

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# **SCIENCE TEACHERS' NARRATIVES ON MOTIVATION AND COMMITMENT – A STORY ABOUT RECRUITMENT AND RETENTION**

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*Abstract:* Evidence of problems in science teacher recruitment and retention are often provided in statistical overviews. The individual science teacher's recruitment is based on subjective motivation, and retention is based on continued motivation and commitment to science teaching. Narratives constitute a way to learn more about the individual teacher's motivation and commitment. Narratives were collected from 10 Danish science teachers, teaching 4<sup>th</sup> to 10<sup>th</sup> year science subjects. This paper focuses on two of these. Their motivation for choosing and staying in science teaching differs. Tina was recruited into science teaching through inspiring teachers in primary and high school and a desire to do good for others; this motivated her to choose teacher education and biology as a major teaching subject. After 9 years of teaching she is retained in teaching by her commitment to treating the children as whole human beings. Jane was recruited into science teaching by an interest in outdoor life; this motivated her to choose teacher education and biology as a major teaching subject. After 32 years of teaching she is retained in teaching by a commitment to developing outdoor science education. Teachers' narratives give individual stories of science teacher student recruitment, as well as retention for in-service science teachers. It is the individual choices of coming and active science teachers that sum up in the recruitment and retention statistics.

*Keywords:* Narratives, Commitment, Motivation, Retention, Recruitment

## **BACKGROUND**

Teacher recruitment and retention has been an area of much interest (e.g. Cooper & Alvarado, 2006; Guarino, Santibanez & Daley 2006; Nordisk Ministerråd, 2009; Hare & Heap, 2001). In many countries there are reports on problems of imminent shortages of science teachers (Danmarks Lærerforening, 2007; National Comprehensive Center for Teacher Quality, 2007). The above studies provide mostly statistical overviews of the problem, which show the magnitude of the present problem and the expected development of the future problem. In Denmark e.g. only 57% of the lower secondary teachers teaching biology have completed subject matter education in biology and only 18% of the teachers teaching primary science have completed subject matter training in primary science (Danmarks Lærerforening, 2007). Such statistics gives an idea of the scope of the problem, but do not provide any insight in the individual teacher's reasons for and approach to teaching science.

Many studies focus on the first difficult years of teachers' professional careers studying different forms of mentor programmes and their effect on the retention of newly started teachers (Ingersoll & Smith, 2004; Hanuscin & Lee, 2008 and Luft, Wong and Semken, 2011). Luft, Wong and Semken (2011) call for a more comprehensive and strategic orientation towards the recruitment of secondary science teachers, and they recommend more focus on the induction period and science teachers' start of their professional career. Such studies on induction programmes are beneficial for expanding our understanding on relations

between recruitment into and the start of science teacher careers, but do not provide insight into the long-term retention over an entire science teacher career.

Recruitment and retention studies on teachers use different approaches such as questionnaires among first year teacher students in order to understand the social and cultural background for recruitment to teacher education (Stage Petersen, 2010); or narrative inquiry in order to understand details in teachers' life and work contexts (Day et al, 2007). This paper will present experienced science teachers' narratives on their experiences in the teaching profession. The research interest is focused on understanding long-term retention through questions on the reasons why the individual teacher chose a teaching career and why the individual teacher chose science as a teaching subject.

## **RATIONALE**

Science teachers' narratives on their choice of education and on their practice is a way to learn more about the recruitment into science teaching as a profession, and the retention in it over an entire career. Persson (2009) interviews teacher students in Sweden and find their recruitment being motivated by experiences prior to starting on teacher education. Using their narratives he is able to describe their subjective motivation for choosing teacher education and to partly understand the underlying social recruitment patterns. He distinguishes between 4 types of motivation: walk in the footsteps of a master, work with your hobby, invest in teacher education, and avoid beers and mopeds.

Day et al (2007) has made an extensive study of teachers' lives, work and effectiveness in the UK using both qualitative and quantitative methods. They distinguish (ibid, p. 213) between two types of retention: a physical continuation, and a maintained commitment and motivation. They base the latter retention type on interview-generated teacher stories and conclude that commitment has major implications for teacher effectiveness.

This paper will discuss these types of motivation and retention using narratives on initial motivation and the commitment of two science teachers in Denmark. The science teacher narratives on motivation and commitment illustrate aspects of recruitment into and retention in science teaching.

## **METHODS**

The narratives were collected in the autumn of 2010 and the spring of 2011 during an ongoing Ph. D. research project in Denmark. The project uses primary and lower secondary school science teachers' life histories to investigate their motivation for and commitment to science teaching. The research design is inspired by Norrie and Goodson (2011) using life-history interviews, observation of the teachers teaching, and collection of materials produced by the teachers such as pupil assignment sheets, subject-oriented letters to parents, and written in-service training assignments, etc. The narratives will be presented in a condensed form in this paper; all translation is done by the author.

The teachers were chosen so that they have several years of teaching experience; such teachers are past the first troublesome years in a teacher career. Their long experience in science teaching makes it possible for them to tell about the long-term retention in focus in this research project.

## **RESULTS**

The 10 teacher-narrators represent 6 schools placed in different socio-economic settings. The teachers have all completed the 4-year teacher education in Denmark; they have attended 3 different colleges of education for their pre-service qualification. They are all qualified for teaching in Danish public education from 1<sup>st</sup> to 10<sup>th</sup> year. Table 1 presents background data of the teacher-narrators' life and education prior to their teaching practice. The two oldest

teachers were recruited directly from high school, whereas the others all had other work or educational experience prior to starting their teacher education. This pattern of delayed recruitment including changes from other careers into teaching has become more frequent during the last decades in Denmark (Stage Petersen, 2010).

Teacher alias	Gender	Year of Birth	High school or similar finished in	Other training or employment prior to teacher training	Start of teacher education	Graduation as teacher
Jane	♀	1954	1974		1974	1978
Erik	♂	1957	1977		1977	1981
Lars	♂	1956	1976	Clerk	1982	1986
Diana	♀	1970	1990	Shop assistant	1992	1996
Linda	♀	1956	1994	China Painter, shop owner	1994	1998
Simon	♂	1971	1990	Laboratory worker	1997	2001
Tina	♀	1975	1995	Kitchen assistant, Videoshop manager	1997	2001
Frank	♂	1973	1997	Farmer, Nursery assistant	1999	2004
Karen	♀	1966	1985	Industrial worker	2001	2005
Ruth	♀	1972	1992	Nursery assistant, Occupational therapist	2002	2009

Table 1: Background data of the 10 teacher-narrators.

The two teachers in focus, Jane and Tina, were chosen since they represent different commitment to and motivation for science teaching. Jane teaches 4<sup>th</sup> to 6<sup>th</sup> year at a school with 400 all Danish-speaking pupils in a small town of 8,000 inhabitants. She is married to a farmer and lives on a farm; she was born in a town 30 km from her present home. Tina teaches 7<sup>th</sup> to 10<sup>th</sup> year at a school in a town of 25,000 inhabitants. The school has 800 pupils of whom 200 are bilingual. She is married to a mechanic and lives in the town where she was born and now teaches. Jane and Tina were both trained at a teacher college (approx. 125 teacher students at each year) close to where Jane now lives. In pre-service education Jane was educated in Biology and Sports as her major teaching subjects, whereas Tina was educated in Biology and Danish.

### Motivation for choosing science teaching

The majority of the 10 teacher-narrators tell that they chose teaching because they care for children and other people. Tina is in accordance with this majority in describing her motivation for choosing teacher education.

Tina: From 1<sup>st</sup> to 6<sup>th</sup> year I had a male class teacher, he was so nice, a very good newly educated male teacher. What he gave us I also wanted to give someone someday.

Jane has another motivation for choosing teacher education; she considered university studies in biology or a career as ballet dancer.

Jane: After high school I wanted to be either a ballet dancer or game biologist, in teacher education I could get a bit of both. The teacher college wasn't that far away, I had a sick mother at that time.

All the teacher-narrators have positive experiences with science education, nature preservation or outdoor life prior to entering teacher training. Jane and Tina illustrate different types of experience that have motivated them to choose biology as a major teaching subject.

Jane: I loved helping out at my uncle's farm. Our holidays were fishing trips. It was obvious for me to choose biology as a subject for teaching, biology has been THE line for me.

Tina: I had the nerdiest nerd in biology in high school, but he was very funny, he had a good approach to biology ... very good at making images in our heads.

Jane's narratives are in accordance with Persson's 'work with my hobby' type of motivation, and she is still very active hunting and caring for game in her spare time. Tina's narratives are an example of Persson's 'walk in the footsteps of a master', she tells of no science or nature related hobbies. The narratives presented are more focused on everyday teaching and less oriented towards conditions of employment than discussed in the literature available in general (e.g. Hare & Heap, 2001; National Comprehensive Center for Teacher Quality, 2007)

### **Commitment to science teaching**

The teacher-narrators have very different reasons for still being committed to science teaching. Jane is committed to improving the possibilities for outdoor oriented science teaching as she has raised money to restore a pond near her school, so that it can be used in biology teaching.

Jane: This pond is a little diamond, but it needs restoration so as not to become choked. You should be able to fish for water insects in it.

Tina has taken on the task of being a coach to pupils with emotional problems and in her biology teaching she puts emphasis on sex and health education, which is part of the biology curriculum in lower secondary school in Denmark.

Tina: I want to have a positive influence on the young people. My attitude is that it is half subject matter and half social worker, because we are to turn whole humans out in the end. I'm developing a curriculum for the sex education at my school.

Tina's commitment is the relation to the pupils and their well-being both physically and emotionally as whole human beings. Jane and Tina both show continued commitment and motivation to developing science teaching at their schools, which is in accordance with the way Day et al. (2007) describe maintained commitment and motivation. The narratives give more positive and affective reasons for staying in the science teaching profession than those provided in the literature in general (e.g. Guarino et al, 2006; Hare & Heap, 2001).

### **CONCLUSIONS AND IMPLICATIONS**

The teacher-narrators carry their initial motivation for choosing teaching into their science teaching practice. Tina was recruited into science teaching through inspiring teachers in primary and high school and a desire to do good for others; this motivated her to choose teacher education and biology as a major teaching subject. After 9 years of teaching she is retained in teaching by her commitment to treating children as whole human beings. Jane was

recruited into science teaching through an interest in outdoor life; this motivated her to choose teacher education and biology as a major teaching subject. After 32 years of teaching she is retained in teaching by a commitment to developing outdoor science education. Despite their commitment to parts of the science curriculum, Jane and Tina teach the entire curriculum of their science subjects with competence.

Teacher education is no longer a frequent first choice of education, which brings different types of experiences of relevance to science into teacher education (table 1). Recruitment to science teacher education could benefit from engaging in initial motivations and prior experiences in order to challenge and develop student teachers' interests and perspectives beyond their immediate motivation for science teaching.

Retention in science teaching can be accomplished through the development of opportunities that support the science teachers' specific commitment. Commitment through participation in on-going changes at their school is typical of all the teacher-narrators as arguments for staying in teaching, not all of these though are related directly to science teaching.

Teachers' narratives give individual stories of science teacher student recruitment, as well as retention for in-service science teachers. It is the sum of individual choices of future and active science teachers that make the recruitment and retention statistics.

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## REFORM IN BIOLOGY EDUCATION: TEACHERS AND RESEARCHERS IN A PROCESS OF NEGOTIATION

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**Abstract:** This study reports the empirical results of the implementation of National Educational Standards in Germany and is part of the transnational European project CROSSNET (Crossing Boundaries in Science Teacher Education). In CROSSNET the term ‘boundary crossing’ is used as a metaphor for a professional learning process in which participants restructure their knowledge and adopt new routines. This process implies collaboration between communities which differ in their routines and practices. In this study the investigated communities are teachers and researchers who cooperate in the German project ‘Biology in Context’ (*bik*). *Bik* aims to promote students’ competencies in context-based biology education and to support teachers’ professional development. Therefore, teachers and researchers work together in Learning Communities (LCs) to transform competency models into practice. The goal of this study is to analyze the processes of boundary crossing in three different *bik* LCs. This analysis is based on Engeström’s activity theory. For the data collection the author uses interviews and protocols of LC meetings as well as instructional materials developed in the LCs. Main outcomes of the study are a better understanding of the elements and the dynamics of this activity system, including the mutual learning process of all participants around context-based and standards-based curricula – the common object of the project.

**Keywords:** biology education, national standards, learning communities, activity theory, boundary crossing

### BACKGROUND AND THEORETICAL FRAME

Facilitating the implementation of National Educational Standards in Germany (KMK, 2004), the project ‘Biology in Context’ (*bik*) aims at promoting context-based and competency-oriented teaching and learning (Elster, 2009; Elster 2010). To support this goal, *bik* uses a ‘symbiotic implementation approach’ (Gräsel & Parchmann, 2004): teachers and researchers build Learning Communities (Brown, 1997) to put theoretically-based competence models into practice. Working together, teachers and researchers develop tasks and units, test them in the classes, and reflect on the participants’ experiences and the learners’ outcomes. In seeking to reform how biology is taught, *bik* puts teachers into a position where they become ‘*at once the targets and the agents of change*’ (Cohen & Ball 1990, p.237).

In this study, the author focuses on the structure and the professional development of teachers and researchers within three independently working *bik* Learning Communities (LCs). The author examines the structure of these three LCs by analyzing teachers and researchers as different ‘sub-systems’.

The theoretical frame of this analysis is based on Engeström’s activity theory (Engeström 2001) which is applied to educational research in the following way: It is assumed that a *bik*

LC is an activity system with two interacting sub-systems: the subsystem ‘Teacher’ and the subsystem ‘Researcher’ (see Figure 1). These sub-systems are the core unit of the analysis. The teacher or the researcher is the *subject* of the interacting subsystem. The initial *object* could be an idea or an assignment that triggers the collaboration of teachers and researchers. The initial object could be ambiguous, requiring interpretation and conceptualization. It could go through multiple transformations until it stabilizes as a finished *outcome*, e.g. a curriculum product. This transformation is made possible by *mediating artefacts*, both material tools and signs. Within a *bik* LC, the members continuously negotiate their *division of labour*, including the distribution of rewards. The temporal rhythms of work, the uses of resources, and the codes of conduct are continuously constructed and contested in the form of explicit and implicit *rules* (Engeström, 2001).

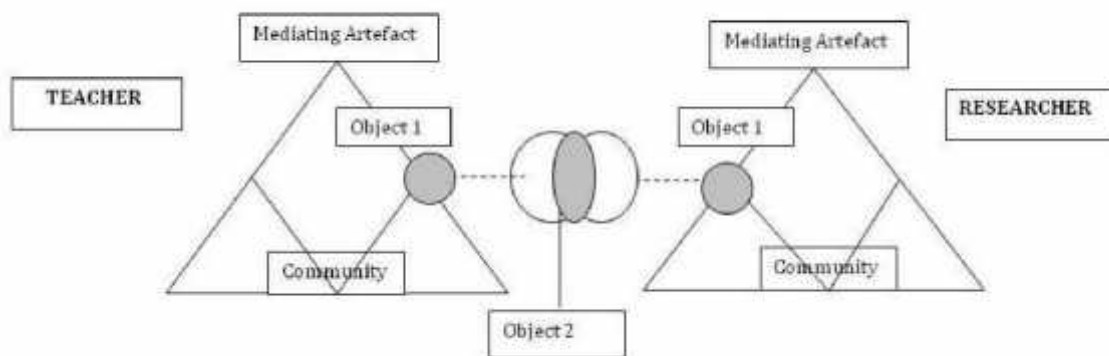


Fig 1: Model of two interacting activity systems (‘Teacher’ and ‘Researcher’), based on Engeström’s activity theory (2001, p.131)

## RESEARCH QUESTIONS AND RESEARCH DESIGN

Based on Engeström’s activity theory (Figure 1) the present study addresses the following research questions:

- Interacting activity systems: How is the subsystem ‘Teacher’ characterized?  
How is the subsystem ‘Researcher’ characterized?
- What are the boundaries of the participating groups and/or individuals?
- What are the outcomes of the boundary crossing process?

The organizational structure of *bik* involved the construction of Learning Communities (LCs) in the nine participating German federal states. Each LC involved collaboration among 8-16 teachers from different schools types. 144 teachers and 1689 students (aged 10 to 17 years; on average 15 years) participated in *bik*. Each LC was chaired by a coordinator and was scientifically supported by a researcher from the German Universities of Kiel, Duisburg-Essen, Giessen, Göttingen, Münster or Oldenburg. The *bik* project was coordinated by the Leibniz Institute of Science Education at the University of Kiel.

In this study, the structure and the development of *bik* in three different Learning Communities were investigated using qualitative interviews, protocols of LC meetings and analysis of instructional materials developed in the LCs. The interview combined questions about the self-concept as a teacher or as a researcher, the concept of teaching and learning, the ‘ideas’ regarding the *bik* innovations (concepts, theories, attitudes), the processes, rules, cooperation

in the learning community. The interviews were taped and later underwent a qualitative content analysis according to Mayring (2000).

## FINDINGS

The findings are structured according to the research questions by (1) analyzing the subsystem ‘Teacher’ (see table 2) and the subsystem ‘Researcher’ (see table 3). Then (3) the boundary crossing process of the participating groups and/or individuals are reported. Finally, (4) the outcomes are analyzed.

### Analysis of the activity systems

Each *bik* Learning Community (LC) is seen as an activity system that consists of two interacting sub-systems, the ‘Teacher’ and the ‘Researcher’. The individual teacher or the individual researcher is the subject of the subsystem. Pairs of teachers and researchers within an LC are the units of the analysis. These pairs are:

LC1: teacher Kathy and researcher Kim

LC 2: teacher Susan and researcher Sarah

LC 3: teacher Joe and researcher Jane

The common goal within the LCs is the teachers’ and researchers’ negotiation of competency models and their transfer into practice. Each LC has its own individual starting points and the initial objects (e.g. competency models) differ from each other. It is assumed that the method and strategy of how these initial objects are transformed into final objects (object 2) are different between the LCs. Object 2 can, for example, be a negotiated concept or material to promote students’ competences.

Table 2. Analyzing the subsystem ‘Teacher’

Sub-system	LC 1	LC 2	LC 3
Teachers	Kathy	Susan	Joe
<i>Similarities</i>	Biology teachers 10 – 20 years of teaching experience		
<i>Community</i>	<p><i>Participants:</i> 7 teachers from different types of school.</p> <p><i>Cooperation:</i> The teachers work in 2-3 small groups on the development of teaching units. They are very critical in the selection of student-relevant contexts.</p> <p><i>Rules :</i> There are no explicit rules that regulate cooperation. Implicit rules are mutual respect, trust, and punctuality. The team’s discussions about norms and values are remarkable.</p>	<p><i>Participants:</i> 13 teachers, mainly from High Schools.</p> <p><i>Cooperation:</i> The teachers work mostly in stable pairs. The researcher Sarah presents example units. The teachers test these materials during the LC meetings and later in their classroom.</p> <p><i>Rules:</i> There are no explicit cooperation rules. The teachers behave more like ‘consumers’ than active developers. They are ‘dissatisfied’ if the input is not school relevant.</p>	<p><i>Participants:</i> 15 teachers from different types of school.</p> <p><i>Cooperation:</i> The teachers work in school pairs or alone. The researcher (supervisor of Jane) instructs the teachers and discusses the competency model in detail. The teachers develop the materials not only during the meetings but mostly as ‘homework’.</p> <p><i>Rules:</i> There are no explicit cooperation rules. An implicit rule is ‘reliability’, i.e. that someone will do his</p>

	<p><i>Division of labour:</i> There are group leaders among the teachers, who dominate the process. The researcher Kim is responsible for new (theoretical) input and for literature research. The coordinator is a teacher mentor who ‘translates’ the teachers’ wishes and the researcher’s demands.</p>	<p><i>Division of labour:</i> The teachers behave like consumers. They are not very active in the production of new ideas. The ideas and concepts come mostly from the researcher Sarah. The coordinator is a well-accepted experienced teacher who sees herself as participant with non-extraordinary rights.</p>	<p>‘homework’ in time.</p> <p><i>Division of labour:</i> The teachers develop building blocks for teaching and learning in school pairs or alone. There is only little exchange of materials among the participating schools. The supervisor dominates the teachers; the doctoral student Jane and the Post-doc Anne are his assistant researchers. The coordination is done by an experienced teacher.</p>
<i>Initial objects</i>	<p><i>Units:</i> Bioethical themes like ‘Pregnancy and abortion’ or ‘Organ transplantation’</p> <p>Typically, the teachers decide the context of the teaching units since here they are experts. The input of the researcher is about the competency model.</p>	<p><i>Units:</i> Learning on stations about ‘How to investigate a river?’ or ‘Which pet suits me and my life?’</p> <p>Typically, the researcher develops ‘example units’ and the teachers are responsible for the further development.</p>	<p><i>Units:</i> Historical experiments about ‘food conservation’, ‘photosynthesis’.</p> <p>Typically, the teachers develop short teaching units that ‘translate’ the competency model into practice in a focused manner.</p>
<i>Mediating artefacts</i>	<p>Syllabi and curriculum plans Student relevant learning contexts</p>		

Table 3. Analysis of the sub-system ‘Researcher’

Sub-system	LC 1	LC 2	LC 3
Researcher	Kim	Sarah	Jane
<i>Similarities</i>	<p>Junior researchers and PhD students Aged 26 – 30 2 -3 years of teaching experience</p>		
<i>Community</i>	<p>Kim is member of a high-level research group, a graduate school, which supports her, especially in methodological issues. Her supervisor allows (or forces) her to foster autonomy and responsibility in the work with the LC 1 teachers.</p>	<p>Sarah is member of a research community consisting of her supervisor, a student partner and an educational graduate school. She has a special feeling for the demands of the teachers. Therefore, during the lifetime of LC2 her specific role in the LC2 changed from an assistant researcher to a well-accepted teachers’ partner.</p>	<p>Jane’s research community is dominated by her supervisor and a female postdoc. Jane receives much support from them but there is much dependence. Jane never leaves the role of an assistant and she is not really accepted as a researcher by the teachers.</p>
<i>Initial objects</i>	<p>Competence model ‘valuing and decision- making</p>	<p>Competence model ‘valuing and decision-making in environmental education for</p>	<p>Competence model ‘knowledge acquisition in</p>

	regarding bioethical issues’.	a sustainable future’.	the field of experimentation’.
<i>Mediating artefacts</i>	<div>Example tasks</div> <div><i>Bik</i> guideline for the development of tasks</div>		

## Boundary crossing in *bik* LCs

To analyze the processes of teachers and researchers in the *bik* LCs we use Engeström’s Expansive Learning Cycle by identifying differences among the LCs regarding the identification of initial questions, the modelling of solutions, the reflection on the process, and the consolidation of new practice (Engeström, 1999).

*Questioning.* The initial questions of the teachers in LC1, LC2 and LC3 were about the ‘new idea’ of the *bik* innovation. Kathy and Susan asked for guidelines and ‘cooking recipes’ for the promotion of students’ competences. Joe asked critically ‘if there is any evidence that the competency-oriented approach is more successful than clear instructions.’ The LC1, LC2 and LC3 researchers developed example tasks to make their competency-models discussable.

*Analysis.* These example tasks were the analysis units in the three LCs. The teachers discussed them during the LC meetings. They compared them with tasks they had traditionally used, and debated the tasks’ possible learning outcomes and how the outcomes could be assessed. In LC 1 and LC 3, teachers who worked in different school types analyzed the practicability of tasks by considering the task performance in the specific school type.

*Modelling new solutions.* The discussions about practicability and assessment of the *bik* example tasks led to a phase of intensive production. The teachers developed new classroom materials. These materials had to be in line with student-relevant contexts and modelling competencies. Two points were remarkable: the teachers needed a longer period of time (about two to three months) to develop the first ‘products’ – tasks that were to be tested in the classroom. The second point was that in LC 1 and LC 2 the discourse of task development led to a power struggle among the participants and to the establishment of sub-groups. In LC 3 the researcher gave ‘homework’ to the teachers where they developed ‘building blocks’ at home and exchanged them via e-mail.

*Examining the models.* In the next step the newly developed tasks and units were discussed in the school teams and examined in the school classes. During the following LC meetings the classroom experiences were discussed. The researchers supported the classroom reflection by offering ‘reflection sheets’. The willingness to discuss classroom experiences was higher than the willingness to write reflections. In all LCs the examination of the self-developed classroom materials led to a new prospering phase: in groups (LC1), in school teams (LC2), or in groups and by individuals (LC 3) a large number of materials were developed and tested.

*Modelling new solutions.* The above led to a second phase of modelling new solutions: the researchers of the LCs came together and developed a mutually shared guideline for the development of *bik* tasks. In annual meetings the teachers demonstrated their developed materials and discussed the practicability, assessment and possible impact of the *bik* tasks.

*Implementation of the new model.* The *bik* materials were disseminated via an internet platform and a CD Rom. The *bik* LCs invited researchers of other LCs to come to their meetings and to inform them about further competency models (e.g. the researcher of LC3 was invited by the teachers of LC2 to introduce them to the competency model of experimentation). During the annual meetings, teachers informed teachers from other LCs

about their work in *bik*, and conducted workshops where they informed about, discussed, and negotiated different *bik* conforming teaching and learning approaches

*Reflection on the process.* The systematic reflection on the negotiation process or on the experiences during the LC meetings and the classroom experiences was a great challenge for the participating teachers. The reasons given were mostly a lack of time or ‘the belief that reflection is not necessary for one’s own professional development’ (final interview with teacher Joe). Therefore, the guideline for *bik* task development was used as a reflection tool. With this tool each task could be analyzed to ascertain to what degree the *bik* goals had been reached.

*Consolidating new practice.* The *bik* outcomes were at different levels. The teachers reported ‘awareness of new ways of teaching and learning’ and ‘new ideas’. Most of them stated their intention to implement the *bik* ideas in their classrooms, but only a few teachers changed their classroom practice fundamentally.

### Further outcomes of the boundary crossing process

*Changes in teaching practices.* The teachers reported several motives for the change of practice. The three investigated teachers, Susan, Kathy and Joe, reported the intention to do things differently in the future (e.g. to be more aware of the students’ interests, to foster students’ communication skills), and the intention to continue new practices. The teachers usually expressed this intention when they had just tested and experienced a classroom experiment successfully. Although the teachers *intended* to change their practices, they rarely reported actual *changes in the classroom*. For the analysis of ‘changes’ we distinguish ‘changed practice’ from ‘temporary experiments’. Only Joe reported that he had changed his practice in a more permanent way and not just for a few lessons (Joe’s report). Kathy and Susan reported that they had not used the new teaching and learning approach often because ‘teaching bioethical dilemmas is only for a few lessons’ (Kathy’s final interview) and ‘students like my lessons about decision-making regarding environmental issues. They make positive remarks, but – on the other hand – I have to continue to teach according to the current syllabus’ (Susan’s final interview).

*Changes of the competency models.* In the three *bik* LCs investigated the initial competency models were changed. These changes were caused by the models’ practicability and their statistical validation. In all cases the models were simplified by reducing their complexity. The reduction of complexity made the competency models easier to handle for the teachers’ task development. In each LC, guidelines on how to plan tasks and units according to the competency models were developed.

## CONCLUSIONS

Summarized, for the analysis of the processes within the *bik* Learning Communities, Engeström’s activity theory has proved of value as a heuristic for the interactions and processes of mutual learning. The main outcome of the study is a better understanding of the elements and dynamics of the activity systems including the mutual learning process of all participants around context- and standards-based curricula (Elster, 2012).

*Traces of mutual learning.* The transformation of the *initial objects of teachers and researchers* (objects 1) to *finalized teacher-researcher objects* (object 2) allows the identification of traces of mutual learning: The *finalized objects* (object 2 in Figure 1) are the concrete products of the negotiation of teachers and researchers. In LC1 these are tasks and units for decision-making in bioethics (e.g. embryo transfer, medically-assisted suicide) in new

student-relevant contexts. In LC2 these are tasks and units in environmental education and sustainability based on a guideline for ethical decision making. In LC3 these are building blocks to foster the competences needed for conducting experiments (generating research questions and hypotheses; planning an experiment; drawing conclusions from the experiment). Furthermore, in LC 3 a complex concept for individualization based on materials about subject-related communication is developed.

*Implementation of an educational reform.* Educational innovations and the implementation of educational reforms succeed or fail not only because of the teachers as ‘targets and agents of change’, but also because of the researchers who are shaping the reform. In the three investigated *bik* Learning Communities the ‘symbiotic implementation approach’ (Gräsel & Parchmann, 2004) leads to the mutual sharing of experiences and concepts, and the establishment of a win-win relationship of teachers and researchers. Based on this relationship the teachers act as partners in the educational reform of the implementation of National Educational Standards in schools. This is considered as one of the traces of success of the *bik* innovation.

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# ACTIVE STRATEGIES DURING INQUIRY-BASED SCIENCE TEACHER EDUCATION TO IMPROVE LONG-TERM TEACHER SELF-EFFICACY

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*Abstract:* Teacher development aimed at increasing the use of inquiry based methods in schools is an important way to reach science learning goals. To this end, the EC has promoted inquiry based science teaching (IBST) within the Seventh Framework Program (FP7). One dimension, typically absent from the FP7 products, is the personal capacity belief of self-efficacy which has been shown to be important to personal behavioral change. The purpose of this research was to develop and test a model of teacher professional development (TPD) which adds specific elements for altering teacher self-efficacies to existing FP7 IBST products. This model was tested for its usefulness in increasing participant self-efficacy as evidenced by short and long term quantitative measures as well as by evaluation of long term inquiry lessons. Workshops to promote IBST were conducted in five different countries. Each workshop included strategies for increasing participant's self-efficacies. Pre and post assessments showed consistently improved personal self-efficacy scores in all of the workshops. In addition, and unlike other long-term studies of teachers, these self-efficacy scores did not significantly diminish over six months. The promotion of self-efficacy in TPD provides a consistent way of evaluating the impact of IBST workshops through the use of changes in self-efficacy.

*Keywords:* self-efficacy, inquiry, teacher development, long-term

## BACKGROUND, FRAMEWORK AND PURPOSE

With dissemination of the results from the TIMSS (Gonzales, P., et al., 2008), PISA (OECD, 2010) and ROSE (Sjøberg, S. & Schreiner, C., 2010) studies, calls for enhanced science teacher professional development in Europe have become more urgent. Improved teacher education both in curriculum and pedagogy has been a suggested response to a lack of student interest and performance among large percentages of secondary science students (Osborne, J. & Dillon, J., 2008). Simultaneously, teacher development aimed at increasing the use of inquiry based methods in schools has been forwarded as an important way to reach these pedagogical goals (see for example, Rocard, M. et al., 2007). Partially in response to these calls for change, the European Commission has promoted inquiry based science teaching (IBST) within the Seventh Framework Program (FP7) through various projects. The plethora of useful materials developed by these and other projects all rely on effective teacher professional development (TPD) to sustainably inculcate science teachers with advanced IBST methods. To accomplish this, the projects typically rely on workshops where teachers are 'trained' in the use of the new materials with more and less success given the difficulties inherent in changing teaching cultures and procedures.

However one dimension, typically absent from TPD from the FP7 products, is the personal capacity belief of self-efficacy which Bandura (1997) has shown to be important to personal behavioral change. While research has not proven a causal relationship between self-efficacy and teaching competence, significant correlations between high teacher self-efficacies and the amenability of teachers to even attempt innovative methods have been found (Ashton & Webb, 1986; Smylie, M.A., 1990). Consequently, incorporating capacity belief change into



professional development programs seems like a worthwhile addition to the FP7 product workshops.

The purpose of this research was to develop and test a model of teacher professional development which adds specific elements for altering teacher self-efficacies to existing FP7 IBST products. This model was tested for its usefulness in increasing participant self-efficacy as evidenced by short and long term quantitative measures as well as by evaluation of long term inquiry lessons. It was hypothesized that self-efficacies could be increased through active influence and inferred that increases would help teachers carry the workshop lessons more successfully back to their teaching.

## **RATIONALE**

Bandura (1997) showed that people act not only because they believe their actions will result in specific outcomes but also because they believe in their own ability to perform them. In science teaching, teachers with high self-efficacies are more likely to use inquiry and student centered teaching methods while those with low efficacies were more likely to be teacher directed (Czerniak, 1990).

Since teaching self-efficacy most typically declines between workshops or pre-service coursework and a year or more of teaching (Andersen, 2004) consequently, actively influencing self-efficacy during TPD may act to retain higher self-efficacies over time. Bandura (1997) established three basic mechanisms by which teacher self-efficacy may be influenced. The most important of these is ‘enactive mastery experience’ where success in teaching with unfamiliar methods, inquiry science for instance, reinforces future teaching. Also influential are ‘vicarious experience’ in which emulating the successful teaching of comparable others impacts self-efficacy as does ‘verbal persuasion’ in the form of credible feedback.

Active use of these mechanisms for changing teacher self-efficacy has been advocated by Bandura (1997) and others, but few studies have controlled and measured consequent effects. Bautista (2011) made extensive use of vicarious and mastery experiences to influence the self-efficacy beliefs of elementary education pre-service students. He did not use ‘verbal persuasion’ since he found it difficult to measure and control during a semester course. He found significant increases in self-efficacy during the study.

## **METHODS**

Teacher professional development workshops to promote inquiry based science teaching for both pre-service and in-service science teachers were planned and piloted in five different countries. A total of 70 teachers participated in the workshops, each of which lasted from one-half to one and one-half days included strategies for increasing participant’s self-efficacies. These methods using Bandura’s three basic strategies for influencing self-efficacy were as follows:

### **Enactive Mastery Experiences**

- During the workshops, participants originated and taught short inquiry lessons to their peers. They received peer-written and verbal feedback about the successful elements of their lessons as well as suggestions for improvement. In the relatively safe and supportive environment of a peer workshop, most had a successful experience with inquiry teaching.

- Participants revised traditional non-inquiry science lessons during workshops and shared their revisions with others. The affirmative feedback they received from the group about their ability to adapt traditional material to an inquiry format was part of a mastery experience.

- All were encouraged to use their developing inquiry teaching skills after the workshops with their own students. In one instance a six-month follow-up workshop was held and participants brought video of themselves teaching an inquiry lesson to their own class.

### **Vicarious Experience**

- Each workshop included examination and analysis of short video segments of science teachers from three different countries teaching lessons which included elements of IBST. Since segments were selected to be realistic with typical teachers, participants could identify with the teachers and imagine themselves also able to do IBST teaching.

- Since each teacher taught a short 'invitation to inquiry' lesson to the workshop participants, each also got to see peers teaching successfully with IBST methods.

- The workshops were completely taught using IBST. To the extent participants could identify with the instructor, they could vicariously imagine themselves also using IBST.

### **Verbal Persuasion**

- During participant IBST teaching, both to the workshops and in one case to their own students, their peers and instructor emphasized the successful elements of their lessons and offered ideas for improvement.

- Feedback to transformed traditional lessons from both peers and the instructor focused on changes consistent for IBST and offered credible further alterations.

Quantitative measures of self-efficacy were made of all participants using the widely used STEBI instrument (Enochs, L.G. & Riggs, I.M., 1990). Both pre-and post-workshop measures of self-efficacy were taken. In the long-term follow-up workshop where participants shared videos from their own classes in which they taught using IBST, self-efficacies were again measured. Observed instances of inquiry teaching both live and via videos were scored for inquiry based on the Science Learning Cycle Rubric developed by Goldston, M.J. et al. (2010).

## **RESULTS**

Participant feedback from the workshops was classified according to Bandura's three basic strategies for influencing self-efficacy. Their comments begin to validate the method of active self-efficacy enhancement in that the participants recognized personal benefits from each of the three strategies. These are examples of the grouped comments:

### **Participant comments relating to enactive mastery experiences**

*'The preparation leading up to making the video involved a lot of discussion and planning. As a result I felt that it pushed us to explore the area more deeply. This is a good thing. I think this stage was a good one if the time is available to do it properly.'*

*'Really good! Yes, such elements should be part of every teacher's education. Working in small groups on preparing has amazing affects on deep discussion of goals and means to achieve them.'*

*'To feel your own body, what works and what captures you.'*

*'Always useful because it gives experience. Feedback was good!'*

*'Involving! Group discussions result in good ideas.'*

*'This was useful. It is about making it practical and discussing it.'*

*'Important to try oneself- having to think a bit further. Something that we are not always good at.'*

*'Useful to find own examples. Easier to change my own teaching after this.'*

*'Own experience and discussions after words were useful. Good to see what others do ... gives ideas.'*

*'Liked the idea with a way of reflecting on the steps I do things like body language and voice.'*

*'Effective and to the point! Performance is reformed by seeing ourselves in action with these goals. It was just 'perfect'. Teachers were natural.'*

*'Fun to test yourself under pressure.'*

*'Good thing so less confident people get to experiment with their teaching style. But go to live teaching shortly afterwards.'*

### **Participant comments relating to vicarious experiences**

*'The videos worked really well. Communication in the classroom is very rich and the videos captured this, particularly the dynamic aspects.'*

*'Videos are very good for discussion so keep those in the modules. Instruction was clear and time sufficient.'*

*'It is useful to have an example in common to talk from.'*

*'Fine to see real teachers in real situations. Good that it is not results we see but something to discuss.'*

*'Ok to start discussions...nice to see 'real' teachers and pupils.'*

*'I learn how to do it by watching. How to spend time and talk to students.'*

*'A concrete starting point for discussion.'*

*'Examples of unknown teachers allow free and open discussions of good and bad.'*

*'Good way to have a common things to talk about. Easier to begin with others.'*

*'Very useful. Group work was very beneficial to apply things.'*

*'To see what is good teaching and what is not. See how students react to both kinds. Discussing how to make bad teaching better. It was all great and very useful. Most interesting and best part of the day.'*

### **Participant comments relating to verbal persuasion experiences**

*'Always useful because it gives experience. Feedback was good!'*

*'Own experience and discussions after words were useful.'*

*'Liked the idea with a way of reflecting on the steps I do things like body language and voice.'*

*'Good thing so less confident people get to experiment with their teaching style.'*

Relative scores on the self-efficacy instrument varied between workshop participants along with their teaching experience and cultural milieu. Quite consistently in all of the workshops however, pre to post workshop scores increased regardless of the original scores. Since the long-term effects of IBST workshops are of particular interest, a group of participants in such a workshop were followed and examined as case-studies. In these cases, pre and post STEBI scores were taken at the start and conclusion of a two-day workshop and again six months later at a follow-up workshop. In addition, participant videos of teaching in their own classrooms were scored. An example of two of these followed cases:

Participant A. During this in-service teacher's participation in the original two-day workshop their relatively high STEBI scores went from 100 to 104 and in the follow-up workshop eight months later, remained relatively high at 106. Consistent with this stability was the rating of 7.5/10 on a video of his teaching. They showed particular strength in providing continuous feedback to the students as they 'inquired' and in maintaining a 'learning cycle' sequence to his lesson. The teacher's students were engaged in an exploration of content which required original thinking in non-formulaic ways. With minimal

instructions and an acceptance of varied solutions, the teacher gave the students opportunities for genuine inquiry and rewarded their efforts by using their solutions for the problem resolution. The teaching was very consistent with the workshop aims.

**Participant B.** This teacher's relatively low self-efficacy score compared to the group went from 84 to 88 during the initial two-day workshop and was stable at 87 in the eight-month follow-up. However, the teacher's inquiry teaching video was rated at 7.0/10 based on a particularly strong student engagement using real world links to student's daily lives. The teacher also had a good extension and feedback. However, the teaching was notably weaker in the inquiry exploration and explanation.

## CONCLUSIONS AND IMPLICATIONS

The use of active strategies to enhance self-efficacy during workshops has been validated through pre and post assessments which showed consistently improved personal scores in all of the workshops. However, unlike a previous long-term study of teachers, this study's self-efficacy scores in the long-term instance did not significantly diminish during the intervening six months (Andersen, A.M. 2004). If through repetition, the active uses of Bandura's (1997) methods for increasing teacher self-efficacy prove to be effective, then their wide-spread addition to IBST modules may be validated. This on-going study's results also provide a consistent multidimensional way of evaluating the impact of IBST workshops through the use of changes in self-efficacy of participants as well as success at using inquiry after workshops back in classrooms. Both outcomes would increase the efficacy of workshop products of EC projects.

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# **SO WHAT IS IT? MAKING SENSE OF THE COMPONENTS THAT CONTRIBUTE TO EFFECTIVE PRIMARY SCIENCE TEACHING**

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*Abstract:* Teachers are key players in the reinvigoration of science education. Unfortunately, the spotlight is often shined on the shortcomings associated with teaching and learning in science. If the status and quality of science education in schools is to improve, efforts need to be made to better understand the classroom practices of effective science teachers.

In a step towards better understanding, the doctoral study gathered evidence examining what two effective primary teachers were doing to promote student engagement in science over a term long sequence of lessons. Evidence of their effective science teaching was gathered primarily through a video-based approach and was supplemented with teacher and student interviews, and student work samples.

Several themes were identified as characterising the practices of these two teachers. These themes form the basis of a conceptual model, which was developed to highlight the various components contributing to effective primary science teaching practices. In teasing out these components, this paper will examine how the teachers' beliefs, knowledge and practices, as well as the contextual factors inherent in their classroom environments, influenced how and why they teach science in the ways they do. While care must be taken in generalising from two cases, these findings have implications for primary science teachers, teacher educators and curriculum developers.

*Keywords:* primary science education, effective practices

## **BACKGROUND, FRAMEWORK AND RATIONALE**

With trends across many countries still indicating the decline of student interest in school science and diminishing numbers of students studying science beyond the compulsory years, it seems that the field remains in crisis. In recognition of the impact that teachers have on student learning (Hattie, 2003), changes to this situation would need to come from teachers who are qualified and committed to science (Goodrum, Hackling, & Rennie, 2001). If these changes are to be realised, an understanding of what constitutes effective science teaching is required and should be addressed.

Reflecting the context of this study, there are three key research documents that have identified characteristics of effective science teaching in Australian schools. These documents are the *National Review into the Status and Quality of Science Teaching and Learning in Australian Schools* (Goodrum et al., 2001), the *Professional Standards for Highly Accomplished Teachers of Science* (ASTA and Teaching Australia, 2009), and the

components of effective science teaching as developed by the *School Innovation in Science (SIS) Project* (Tytler, 2003). These three documents provide rich, detailed descriptions of what characterises the strategies, attributes and environments of effective science teaching practices. The frameworks that these studies provide are useful tools in better understanding the different aspects of effective science teaching and learning. In their synthesis of these documents, Hackling and Prain (2005) identified a strong convergence around six characteristics of effective science teaching:

1. students experience a curriculum that is relevant to their lives and interests;
2. classroom science is linked with the broader community;
3. students are actively engaged with inquiry, ideas and evidence;
4. students are challenged to develop and extend meaningful conceptual understandings;
5. assessment facilitates learning and focuses on outcomes that contribute to scientific literacy; and
6. information and communication technologies are exploited to enhance learning of science with opportunities to interpret and construct multimodal representations.

(Hackling & Prain, 2005, p. 19)

However, while these identified components may help to shed light on the nature of effective science teaching, on their own they cannot bring effective science teaching to life. Effective science teachers may be able to demonstrate particular attributes, but little is understood about precisely what beliefs and knowledge drive their practice. Therefore, it is not clear why effective teachers' actually do what they do.

The overall purpose of this doctoral study was to collect evidence about what effective primary science teaching looks like over a term long sequence of lessons and to explore the relationships existing between teachers' beliefs, knowledge and their practice. This paper will report on the findings gathered from two primary school science teachers involved in this study, Deanne and Lisa. In particular, the following research question will be addressed: what characterises the practice of an effective primary science teacher?

## METHODS

This study was qualitative in nature and incorporated ethnography with an interpretive case study approach (Merriam, 1998). These methods were used to reflect the complexities inherent in teaching and in coming to better understand the practice of teaching, as well as to allow for the recreation of a rich and vicarious experience for the reader (Peshkin, 2000). This section provides an overview of the research design used for this study by outlining the participants and data gathering techniques used during the data collection process.

The participants in this study were two primary school teachers, identified as effective practitioners of science by a professional colleague, and their students. At the time of the study, Deanne was teaching a Year 7 class and Lisa was teaching a Year 3 and 4 class. Year 7 is the final year of primary school in Western Australia, the Australian state where this research was conducted. A focus group of four students was formed in each class.

Observations were carried out in each teacher's classroom over one school term (10 weeks) during their weekly science lessons (each approximately one-and-half hours in length). Three video cameras captured each science lesson with one camera tracking the teacher, one camera focused on the focus group students, and the other camera was fitted with a wide-angle lens

to focus on the whole class. Following each classroom visit, semi-structured interviews were conducted with Deanne and Lisa with each interview approximately 40 minutes in length. The focus group students from each class were also interviewed after each science lesson. These students were interviewed as a group with each interview taking approximately 10 minutes. Written documents were also collected from the two teachers and their students over the unit, such as unit plans, worksheets, assessment items and work samples.

The data collected from the multiple sources were examined for the practices characterising Deanne and Lisa's approaches to science teaching and learning. A process of ethnographic microanalysis, as described by Erickson (1992), was used to analyse the data from the video footage, interview transcripts, and work samples. Data sources were watched or read several times and events, episodes and quotes were identified that provided supporting evidence for the emergent themes. Several themes emerged from the data and were identified through being mentioned or observed numerous times. The emergent themes were presented to both teachers for further clarification.

## RESULTS

This research resulted in five general assertions (GA) being developed to describe the influence of effective science teaching practice on student learning in science. These five general assertions were:

- GA 1: Teaching for student engagement in science;
- GA 2: Providing students with concrete experiences in science
- GA 3: Supporting student learning in science
- GA 4: Monitoring students' learning in science
- GA 5: Developing scientifically literate students

The model below (see Figure 1) was synthesised from the general assertions that emerged from the analysis and interpretation of the multiple data sources. This representation identifies the interacting components that characterise the similarities inherent in the effective science teaching practices of the two teachers.

The components of the model are described, in relation to the five general assertions, in the following text. Deanne and Lisa used concrete experiences of science to provide students with opportunities to explore science phenomena first-hand (GA 2), engage in meaningful talk about science (GA 3) and provide a context for the construction and use of multi-modal representational forms (GA 3). They actively monitored these learning experiences and provided students with constructive feedback regarding their learning (GA 4). These components are embedded within inquiry-based approaches to science teaching and learning, which acted to promote student interest and engagement (GA 1). Through nurturing student understandings and positive attitudes towards science (GA 1), Deanne and Lisa supported students in becoming scientifically literate citizens who are capable of engaging with science issues relevant to their lives and their communities (GA 5). Underpinning these practices are beliefs, knowledge and contextual factors, which directly impact on teachers' orchestration of learning to meet their particular students' needs in the contexts in which they work.



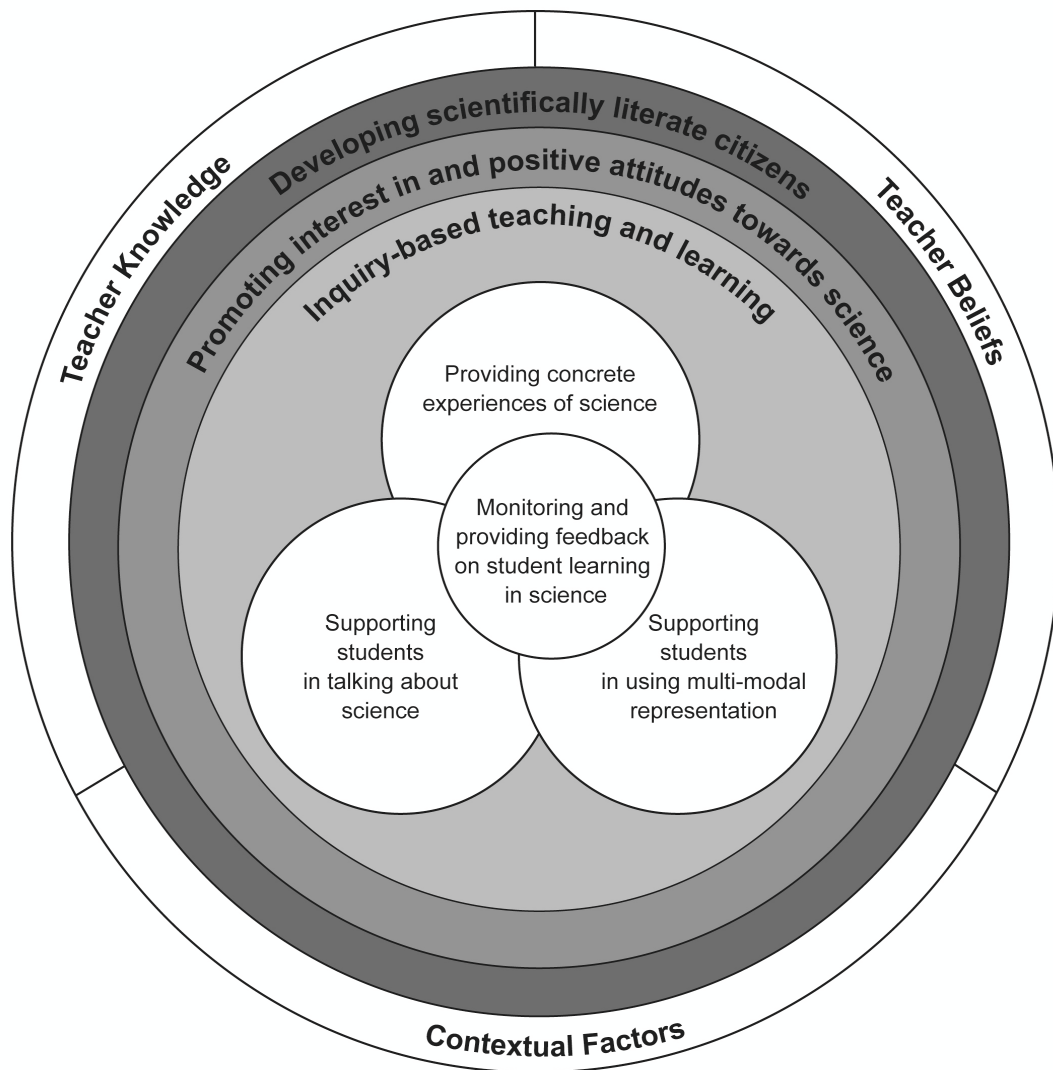


Figure 1. Conceptual model of components contributing to effective primary science teaching

## CONCLUSIONS AND IMPLICATIONS

The tendency for primary school teachers to avoid the teaching of science has been well documented (e.g., Tytler, 2007). Research has suggested that as little as three per cent of teaching time, on average, is allocated to the teaching of science in Australian primary schools (Angus, Olney & Ainley, 2007). Other research has demonstrated that interest in and attitudes to science learning are entrenched in 14-year-old students (e.g., Lindahl, 2007). When combined, these findings concern all stakeholders in primary science education. The primary school years are therefore a crucial time for capturing students' interest in science and the development of understandings of what constitutes effective science practices in the primary setting are of key importance. While this research contributes to the existing knowledge base and literature, a more comprehensive understanding of what constitutes effective primary science teaching and how it is influenced by teachers' beliefs and knowledge, as well as contextual factors, is needed if we are to better support primary school teachers in the practice of teaching science.

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# INNOVATIVE SCIENCE TEACHERS: WHAT THEY HAVE IN COMMON

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*Abstract:* Changes, in general, in science education require that teachers play an additional role different from their traditional model. However, in Brazil teacher education policies do not provide the necessary conditions for changing the role of the teacher. In the Brazilian context, at least for public schools, science teachers do not have many opportunities for innovative practices as there are a number of factors that can prevent it from occurring. Nevertheless, even in this unfavorable context, some science teachers create new ideas (e. g. curriculum development projects), and innovate their pedagogical practices. This study seeks to identify professional characteristics of innovative science teachers that even without support or time, they innovate their pedagogical practices. We used different research techniques including open-ended and narratives interviews (2010) and participant observation with two science teachers from elementary schools. The teachers were observed for three years (2008-2010). The data showed that these professionals have some characteristics in common: they create innovations by themselves; participated in new school' curriculum development projects, they regularly participated in continuing education programs, they were more motivated to enhance their daily pedagogical practices, and they had a social commitment to students. Understanding these professional characteristics can assist school principal and pedagogical coordinator to promote, encourage, and support science teachers in creating and participating of innovation.

*Keywords:* Innovation. Changing. Science teachers.

## INTRODUCTION

Changes in science education require that teachers play another role different from a traditional way of teaching. However, in Brazil the teacher education policies do not provide the necessary conditions for changing teachers' practices. Thus, science teachers in most classrooms do not innovate and change their pedagogical practices, related primarily to traditional content exposure, and the use of traditional pedagogical tools such as blackboards and textbooks.

Innovation is defined as a set of interventions and decisions with a certain degree of intentionality (FULLAN, 2001; CARBONELL, 2002; CARDOSO, 2003). According to Carbonell (2002) it can be used to stimulate theoretical reflection of the teachers' experiences and promote interactions among students.

Many factors influence innovations. Among them are: culture of school, teachers' conceptions regarding teaching and learning.

In another study (Garcia, 2009) it was demonstrated in a Brazilian context that some factors prevent science teachers practicing innovation (e. g. lack of time to discuss the problems of implementation and the development of innovation in school). This is opposite to the simplistic view from that tend to blame science teachers for lack of innovative practice. Others factors that also prevent innovations are the poor working conditions, new laws that

overload teachers' practice with more assignments and responsibilities, traditional pre-service education program, the role of principals in schools, and the teachers general lack of knowledge and beliefs in innovations being proposed.

Nevertheless, even working in unfavorable contexts for change some science teachers seek new alternatives, and in fact do innovate.

We believe, as Cardoso (2003), that there are many variables involved in the process of teacher-as-innovator. These include: *organizational factors* (those linked to encouraging climate that can favor personal initiative), *professional* (those related to professional activities); *personal* (those linked to teacher's attitudes related to innovation receptivity) *demographics* (gender, age, work experience), and *personality* (linked to a greater or lesser predisposition to innovation).

In this study we are particularly interested in identifying professional characteristics (variables) that are common about science teachers' daily pedagogical practices. Understanding these professional characteristics can assist school principal and pedagogical coordinator to promote, encourage, and support them at school, favoring, in this way, science teachers to create and participate of innovation.

## TEACHERS AND INNOVATIONS

Despite its ambiguous character, innovation refers to a set of interventions and decisions with a degree of intentionality and systematization, which aim to transform attitudes, ideas, culture, content, pedagogical models and practices (FULLAN, 2001; CARBONELL, 2002; CARDOSO, 1997).

The implementation of innovations, according to Fullan (2001: p. 75-80), is affected by a set of interactive features. Among others, is the need for change and clarity about the goals and objectives. Innovation also depends on the culture of the school, the teachers' conceptions about teaching and learning, and still need time and support to be implemented.

In recent years, reforms and innovations implemented by governments have failed to transform, for example, science teachers' practices that continuing being traditional. This is because, in part, in Brazil policies for teacher education have not produced the necessary conditions for a significant change in the role of the teacher. Many science teachers, however, have the desire to change, but they are working in systems, schools, and with professionals who do not promote innovation, and often even functioned as obstacles to change (GARCIA, 2010).

Some authors have already identified some obstacles related to innovation. Among them are the overload of work (HARGREAVES & FULLAN, 2000), individualism of the profession (HARGREAVES & FULLAN, 2000; THURLER, 2001), organization and operation of the school (THURLER, 2001), the meaning of innovation (HARGREAVES, EARL & RYAN, 2001; THURLER, 2001, FULLAN, 2001), the issue of time to perform the change (HARGREAVES, EARL & RYAN, 2001; CARBONELL, 2002; FULLAN, 2001), lack of support for teachers make concrete changes (FULLAN, 2001; CARBONELL, 2002), the way the school principal work (THURLER, 2001), the reflection of failed innovations on future projects (HARGREAVES & FULLAN, 2000; THURLER, 2001), lack of time to discuss the problems of implementation and the development of innovation in school (GARCIA, 2009).

Garcia (2009, p.55) identified some factors that difficult science teachers to innovate: personal factors (lack of interest in participating in the project, fear, insecurity), professionals

(lack of encouragement, support and time, inability of those who run the project, overwork and lack of learning) and contextual (lack of material and financial resources).

However, it is worth noting that some science teachers, even working in some unfavorable contexts with many obstacles, as described earlier, they still innovate in their classrooms. They have a change as an integral part of what they believe in their work. Create new practices, being receptive to others, participate in projects is part of what they believe about teaching and learning. In other words, innovation is part of their personal views of teaching and learning in schools.

Beside this, in a study about pedagogical innovations at the university, Cunha (2004) showed that teachers who innovate have some common characteristics. They enjoy teaching, are dedicated to their work, more enthusiastic about their practices, more critical and satisfied with what they do, and have a social commitment to students and to school community.

Cardoso (1999), on the other hand, tried to understand the correlation between teachers' receptivity to innovation associated with other variables such as experience in teaching and continuing education. The author found, although weak, positive correlation between continuing education, (in terms of participation in courses (congresses, conferences), publishing scientific articles, and research projects inside and outside the school), and receptivity to innovation. That is, teachers with greater participation in these three levels also had more favorable attitudes to pedagogical innovation.

## **METHODS**

This study aims to identify common professional characteristics in two science teachers who innovate constantly in their teaching practices. To answer this question we selected two science teachers who work in elementary education in public schools in Sao Caetano do Sul, a province/state near Sao Paulo - Brazil.

These two teachers were selected from a group of 20 teachers who taught in elementary public schools. Our choice was based on their classroom performances in schools and specifically their teaching of science classes. These teachers regularly created innovative pedagogical practices, participated in other school-based initiatives, they were constantly involved in continuing education, and also involved in activities with their students, which included field trips.

Data were collected through participant observation and interviews. It is worth noting that the researcher was also the responsible for promoting science continuing education for these two teacher participants and, therefore, spent three to five hours per week with them.

The observations were conducted for approximately three years, once a week (on alternate days) for duration of two hours. The observations were made using protocols of research adequately developed to collect information on: 1) number of innovations created, 2) participation in the school's innovations, 3) participation in continuing education projects, 4) involvement with students, 5) involvement with parents, and 6) professional connections.

The interviews (2010) collected information on 1) teachers' profile (gender, age, education, teaching experience, teacher workload, per week), and 2) on the teachers' triggering reasons to innovate. Narrative interviews were also conducted in order to understand more about their personal and professional trajectories, however these data are still being analyzed.

We also interviewed:

- A) a group of 10 students about these two exceptional teachers in 2008, 2009, and 2010 (different students each year) to know: 1) students' view over his/her teacher, 2) students' view over his/her teacher' classes (his or her pedagogical practices) 3) students' view over the relationship between them.
- B) the pedagogical coordinator from both schools.

## RESULTS AND DISCUSSION

The participants were one male (55 years-old) and one female (45), both with over 20 years of teaching experience. His undergraduate degree majored in Science and Biology, and worked in two public schools and with a workload of 45 hours-class per week. She majored in Science and Chemistry, worked in a public school with 26 hours-class per week. Both had experience with some postgraduate science courses.

From the interviews we highlight the reasons about their willingness to engage in pedagogical innovations. With very similar responses, both research participants attributed this approach to innovation based on their beliefs about education; that is, their conceptions of teaching and learning, which was also confirmed by observations. They valued and believed that innovations could motivate students and at the same time improve their pedagogical practices. This finding was also found by Anderson (1989) when he affirmed that the conceptions act as personal theories that lead, among other things, pedagogical practice of teachers.

From interviews we highlight two other results that are explained below:

She indicated that she could be innovative because the school's atmosphere offered a perfect scenario to create new curriculum and pedagogical projects. He, on the other hand, stated that he used to innovate because that was part of his daily life. This reason may be linked to his personality and not necessarily to his views of education. The narrative interviews which we are still analyzing may explain more about this finding. It is interesting to note that both teachers were enthusiastic about teaching science, and had a social conscious about students as it was already described by Cunha (2004). This commitment was expressed, among other things, meetings with students inside and outside working hours, educational programming outside of school with students, with respect to organizing and supervising visits with students to museums.

Data from observations showed that the two teachers created at least one innovation each year. They also participated in any new school projects being organized during every year of the observations. They were constantly engaged in continuing education in their workplaces. The male participant was involved in independent professional development courses at universities as well. In fact, teachers-as-learner was a permanent characteristic of both teachers. This again confirms what Cardoso (1999) found in her quantitative study about the positive correlation between continuing education and the receptivity to innovation.

Both participants were regularly trying to find new contents from newspapers, scientific journals to bring to their students. They were commonly involved with their students, although he promoted more pedagogical studies outside the school. They knew, for example, students' name, students' difficulties and had good teacher-student relationship with them. They were viewed by their students as being more democratic and good teachers in general. Finally, these professionals had contacts with networks of collaborators outside the school, generally associated with colleges and universities.

The school and the school principal also considered them excellent teachers. They were, generally, in the school staff meeting more critical they asked more questions, and discussed and criticized the ideas that were being discussed.

Interviews with the two pedagogical coordinators (PC) of schools showed that they also considered the two teachers as innovators, because they were always "creating, inventing, taking part in something at school or community" (PC01). One of the coordinators also said that in school meetings the teacher demonstrated to be more critical and has a more elaborate discourse about pedagogical practices (CP02).

## FINAL IMPLICATIONS

We highlight some professional characteristics that are common in both teachers: 1) involvement with continuing education, 2) motivation with the pedagogical practices and 3) social conscious about their school community.

These professional characteristics have direct implications for school principals and pedagogical coordinator for the school and school district. School and district administrators can act to promote a better atmosphere to develop, encourage, and support these professional characteristics at school amongst all teachers. This will help science teachers to gain confidence and begin pedagogical and curricular innovations and, at the same time, participate with other teachers with the objective of assisting students in their process of learning science in schools.

On one hand, the implications of those conclusions bring the need to ensure a deep understanding of several variables involved in innovation process. On the other, it indicates that larger investments in the quality of science teachers' initial and continuing education especially in support to school-based professional development, may favor science teachers in the process of creating innovative pedagogical practices.

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## HOW DO IN-SERVICE TEACHERS EVALUATE THE COGNITIVE/LINGUISTIC SKILLS IN THE STUDY OF ASTRONOMY?

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**Abstract:** The aim of this study is to find out how teachers of the last years of Primary and the first years of Secondary evaluate and what difficulties they find in relation to a series of cognitive- linguistic skills (description of facts and observable phenomena, description of theoretical models and justification of the phenomena using theoretic models). It also aims to find out whether teachers establish differences when the skills are expressed in a general sense or when they are associated to the subject of astronomy.

In the study, 113 Primary and Secondary teachers from different centres in Galicia (Spain) who responded to a closed survey took part. The results show that the teachers positively evaluate the skills presented, with changes being seen in terms of content. The description of facts/phenomena is considered more in generic terms and those skills which require more abstraction, in astronomy terms. The teachers attribute more difficulty to the latter skills in the generic principles than in the astronomy ones.

The few differences between the groups of teachers are in the evaluation of the description of models and in the difficulty attributed to some skills that require more abstraction from the primary group.

**Keywords:** Teaching thought. Active teachers. Primary. Secondary. Astronomy

### INTRODUCTION

Communication is very relevant in the teaching of sciences (Jim3nez Aleixandre, 2003; Mortimer, 2006). For this reason, the development of different cognitive-linguistic skills is important, such as for example: the description of a fact or phenomenon; of a theoretical model and the justification which explains why this phenomenon is produced, by using an accessible theoretic model with students of a certain age (Jorba et al., 2000). They are all necessary and they should be promoted in different subjects in a balanced manner. There is no sense in teaching a model if it is not going to be used in order to justify an act/phenomenon.

In particular, in the subject of astronomy the description of the models (Earth rotation/ passage) is insisted on more than the observation of the sky. Teachers may feel uncomfortable focusing their attention on the direct observation of the movement of the stars throughout the day and night as this involves carrying out a geocentric interpretation. Therefore, it is immediately clear that what we observed is not “right” (Shen & Confer3, 2010). However, despite the importance that teaching staff seem to give to knowledge of the theoretical models, they have difficulty in working properly with the model in the classroom (Justi & Gilbert, 2002).

The teachers' way of thinking is an important factor in the change and improvement of teaching, therefore knowing their opinions is essential for improving their professional development and the quality of teaching (Van Driel, et al. 2001; Mellado, 2003).

In accordance with the aforementioned, our objective is to find out how practicing teachers in the last years of Primary and the first years of Secondary evaluate certain cognitive-linguistic skills when they are expressed in generic terms and when they are associated to astronomy content. We also intend to find out the difficulties the teachers attribute to these skills.

## METHODOLOGY

A closed survey was carried out of 113 practicing teachers (59 from the last year of Primary (students from 9-11 years old) and 54 from the first year of Secondary (12 to 14 years old), from different schools in Galicia (number of teachers per centre always <3).

The participants evaluated on a scale of 1 to 5, the importance and difficulty of some language-related skills: description of facts and/or phenomena, description of a theoretic model and their justification. The skills were stated generically and they were associated to their knowledge of astronomy. Specifically, the teachers had to evaluate the importance and difficulty of generic abilities expressed in the following terms: a) "describe facts and natural, observable, everyday phenomena, such as the movement of objects, changes of state, rainbows, etc."; b) "describe un-observable processes, such as digestion in human beings, or describe more or less simple scientific models, such as a model of a cell or the Earth, etc."; c) "justify facts or phenomena by using a more or less simple scientific model, such as justifying a change of state using a particles in movement model or justifying the phases of the moon with the Sun/Earth/Moon model". Furthermore, the teachers had to evaluate the importance and difficulty of cognitive-linguistic abilities which involve the expression of certain astronomic statements about daily and annual changes. The statements were the following: a) *"The Sun moves in the sky from east to west throughout the day"* and *"In areas with mild climates there are seasons and the number of daylight hours and the height of Sun varies throughout the year"* (these statements involve the description of facts/phenomena); b) *"The Earth is a spherical shape, it rotates on its own axis"* and *"Earth with its inclined rotation axis revolves around the Sun"* (these statements involve the description of models) and c) *"The sun seemingly moves through the sky during the day because the Earth rotates around itself"* and *"In temperate zones of the planet, both the number of hours of light and darkness and the height of the sun at midday change regularly throughout the year, due to the inclination of the Earth's axis and its movement around the sun"* (these statements involve justification). The summary of statements and codes can be seen in Table 1.

In the analysis of results the following was used: a) the McNemar test in order to detect differences between the maximum evaluation/difficulty granted to the different principles within each group of teachers and b) the Pearson  $\chi^2$  in order to identify differences between both groups. The statistics programme SPSS was used (significance value  $p < 0.05$ ). An individualized analysis of the evaluations of each teacher was also carried out, independently of the evaluation, in order to see which skill was granted higher importance or level of difficulty (see types of evaluation, Figures 1 and 2).

## RESULTS

The majority of the teachers gave the maximum points to the different principles. All of them receive a value 4 or 5 from more than 50% of the teachers (Table 1). Significant differences can be seen between the principles, in particular: a) in the generics, G-FD is more important than G-MD in the Primary group ( $p=0,001$ ); b) in the daily changes, D-MD taken more into consideration in the Primary group ( $p=0,031$ ;  $p=0,022$ ) and more valued than D-FD, in the

Secondary ( $p=0,049$ ) and c) in the annual changes, A-FD is valued more than A-MD in Primary ( $p=0,031$ ). When comparing the generic and astronomic principles, it can be seen that in Primary D-MD is more valued than its generic counterpart (G-MD) ( $p<0,000$ ) and in Secondary the opposite occurs with D-FD (less valued than G-FD) ( $p=0,04$ ).

Table 1. Teachers who award maximum importance and difficulty (values 4 and 5) to the different principles (generic and astronomy)

Category/Principles		Importance		Difficulty	
		Prim.	Secon.	Prim.	Secon.
Generics	G-FD Describe phenomena and natural facts	49 <sup>(1)</sup> (83.1%)	45 (83.3%)	23 (39.0%)	13 (24.1%)
	G-MD Describe models or non-observable processes	34 (57.6%)	44 (81.5%)	44 <sup>(1)</sup> (74.6%)	37 <sup>(1)</sup> (68.5%)
	G-J Justify facts and phenomena using a simple model	38 (64.4%)	41 (75.9%)	44 <sup>(1)</sup> (74.6%)	32 <sup>(1)</sup> (59.3%)
Daily changes	D-FD The Sun moves in the sky from east to west throughout the day	43 (72.9%)	32 <sup>(2)</sup> (59.3%)	28 <sup>(1)</sup> (47.5%)	18 <sup>(1)</sup> (33.3%)
	D-MD The Earth is a spherical shape, it rotates on its own axis	53 <sup>(1)(2)</sup> (89.8%)	41 <sup>(1)</sup> (75.9%)	15 <sup>(2)</sup> (25.4%)	6 <sup>(2)</sup> (11.1%)
	D-J The apparent movement of the sun is explained by the Earth's rotation	44 (74.6%)	36 (66.7%)	31 <sup>(1)(2)</sup> (52.5%)	18 <sup>(1)(2)</sup> (33.3%)
Annual changes	A-FD In areas with mild climates there are seasons (n° of hours of light and height of Sun varies)	39 <sup>(1)</sup> (66.1%)	40 (74.1%)	20 (33.9%)	10 (18.5%)
	A-MD The Earth with its inclined rotation axis turns around the Sun.	30 (50.8%)	40 (74.1%)	41 <sup>(1)</sup> (69.5%)	16 <sup>(2)</sup> (29.6%)
	A-J The seasons are due to the inclination of the axis of the Earth and to its passage	32 (54.2%)	36 (66.7%)	39 <sup>(1)</sup> (66.1%)	30 <sup>(1)</sup> (55.6%)

- (1) Assessment/consideration of difficulty significantly higher than all or some of the principles of their category (test McNemar;  $p<0,05$ )  
 (2) Assessment/consideration of difficulty significantly differs from its generic counterpart (test McNemar;  $p<0,05$ )

The teachers recognize difficulties, detecting the following differences: a) in generic principles, G-MD and G-J are more difficult for both groups ( $p<0,000$ ); b) in the daily changes, D-MD is more simple for both groups (Primary  $p=0,004$ ; Secondary  $p=0,008$ ) and c) in the annual changes, A-MD and A-J in Primary and A-J in Secondary are considered more difficult than A-FD ( $p=0,002$ ). Moreover, the secondary teachers see more difficulty in the more abstract generic principles (G-MD and G-J) than in their astronomy counterparts ( $p<0,000$ ) except in the case of AJ. The same happens in the Primary group, but only for daily changes (D-MD  $p=0,000$  and D-J  $p=0,02$ ).

Using the Pearson  $\chi^2$  test, differences are detected between the groups of teachers. The principles G-MD and A-MD are more important for the Secondary group ( $p=0,006$ ;  $p=0,01$ ) and D-MD for the primary group ( $p=0,048$ ). The principles D-J and A-MD are more difficult for the Primary teachers ( $p=0,04$  and  $p<0,000$ , respectively).

The comparative analysis of the evaluations of each teacher (Figure 1), shows that for the two groups, type A (the description of facts/phenomena is valued more) is the most frequent in the generic principles. However the frequency decreased in the case of the astronomy principles (daily changes in both groups and annual changes in Secondary). With regards to difficulty (Figure 2), type B (the abstract skills being more difficult) is the most numerous in the generic principles and in the annual changes. However, in terms of the daily changes, more than 40% of the subjects show type A opinions.

Figure 1. Percentage of teachers that: **A** (value FD more than MD and/or J; **B** (value MD more and/or J than FD); **C** value all the principles equally

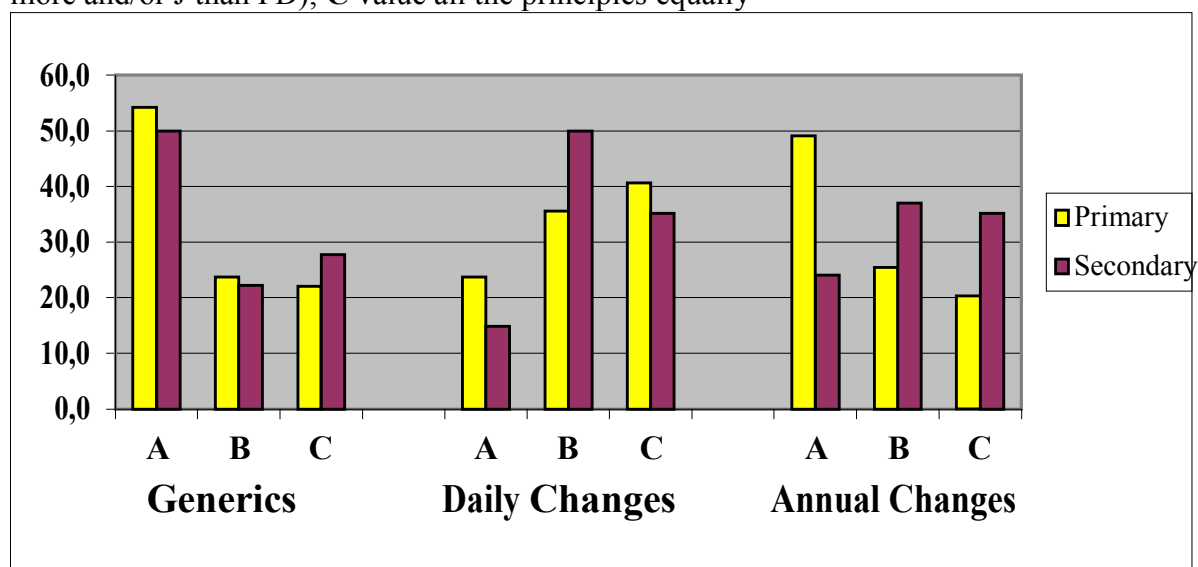
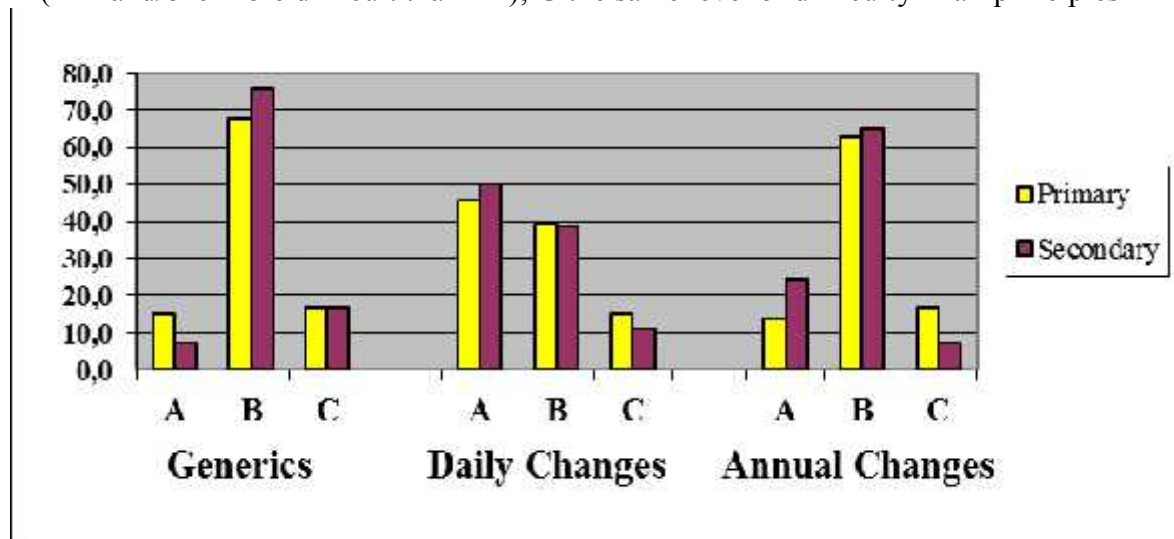


Figure 2. Percentage of teachers that consider: **A** (FD more difficult than MD and/or J); **B** (MD and/or J more difficult than FD); **C** the same level of difficulty in all principles



## CONCLUSIONS

The teachers positively evaluate the cognitive-linguistic skills, seeing differences in accordance with the content. In general, the description of facts/phenomena is considered more in generic terms and the skills that require more abstraction are valued more in relation with astronomy knowledge.

The teachers attribute more difficulty to generic skills that require more abstraction than their counterparts associated with astronomy aspects.

Few differences are detected between the groups of teachers. They focus on the evaluation of the description of models and on the difficulty attributed to some skills that require more abstraction by the Primary group.

This seems to demonstrate that the teachers do not sufficiently value the observation of astronomy phenomena and that they do not always perceive the difficulty of the use of the model and justifications, at least in the case of the daily changes, despite its complication (Baxter, 1989). We understand that the permanent training should focus on the importance of observation, as it is a key aspect which is going to favour the establishment of questions and open the way to the use of explanatory models and to the justification of the facts observed. To achieve this, a recent study (Navarro, 2011), recognising the importance of the observation of the sky, suggested a teaching proposal based on the resolution of problems and it was successfully developed in a Primary classroom. The ideas of the students evolved satisfactorily.

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## SCIENCE TEACHERS' ATTITUDES AND PERCEPTIONS RELATED TO PRACTICAL WORK: A SELF REPORT QUESTIONNAIRE

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*Abstract:* The purpose of this study was to develop a self-report questionnaire, valid and reliable, to explore teachers' attitudes and perceptions related to practical work. We also aimed to apply the questionnaire to a random sample of secondary teachers and provide data contributing to a characterization of teachers' attitudes and perceptions on practical work. Our motivation to conduct this study comes from the renewed emphasis in enquiry based science teaching and practical work in the most recent curriculum reform for secondary science education. The questionnaire, after trialling, pilot studies and consequent refinement, has proven to be a useful research instrument to identify general and individual tendencies. The initial tendencies identified in teachers' responses suggest good predisposition and benevolent attitudes in general; however these contrast with some teachers, reluctance to practical work, lack of confidence and sense of control. We recognize that our questionnaire is useful to explore teacher thinking but it needs to be complemented with other relevant sources of information like ongoing in-depth interviews to explore the challenges and opportunities of using practical work to develop conceptual understanding and process skills. We see this study as a starting point for further research on effective ways of supporting teachers to develop skills and awareness on the potential and limitations of practical work.

*Keywords:* secondary science teachers; practical work, teacher attitudes; teacher perceptions, questionnaire development.

## INTRODUCTION AND BACKGROUND

Secondary school science teachers usually have to teach a wide and demanding curriculum. The problem of how to support them in initial and in-service training, and to develop the basic knowledge, strategies and skills that they need as practising teachers is still faced by teacher educators around the world. In Mexico, with the recent introduction of a new secondary science curriculum, enquiry based teaching and aspects of the nature of scientific enquiry have a renewed emphasis in the normative pedagogical discourse and associated materials. Teachers are encouraged to incorporate practical work systematically in their practice as in other countries (Anderson, 2007). This places significant demands on the teaching force, given the fairly modest science background of most Mexican secondary school teachers, and the limited opportunities provided to them to be engaged in practical work and investigative processes during their own education and training.

The role of practical work in science education has been widely discussed (Millar et al., 2002; Berg et al., 2003; Lunetta et al., 2007). In this paper, by 'practical work' we mean

any teaching and learning activity that engages teachers and students in observing or manipulating concrete objects and materials (Millar, 2004). This term is used in preference to ‘experimental’ or ‘laboratory work’, in order to include those activities involving observation or manipulation conducted in and out of the school setting. Standing from a situated perspective (Brown, Collins and Duguid, 1989), we are aware that many contextual and social elements are involved in complex human interactions such as teaching. Teachers inevitably develop their own perceptions and attitudes towards practical work; those perceptions, in turn, might interact with curriculum demands. Moreover, such attitudes are likely to be reflected in their discourse and actions and may have influence on the activities they provide for students, how they organise and manage their classroom, what role they adopt, the way they use equipment and materials, and the criteria they use in assessing the success of practical work (Abrahams & Saglam, 2010).

As a way to systematically explore secondary science teachers’ perceptions and attitudes related to practical work, we report here the design and development of a questionnaire. The development of the questionnaire was conducted in the context of a larger project oriented to perform a diagnostic study on the use of practical work in science education in public secondary schools in Nuevo Leon, a state in the North-East region of Mexico. Such project also intends to inform the elaboration of teaching materials based on practical work to support the official curriculum. Consequently, our aims were:

- To develop a self-report questionnaire, valid and reliable, to explore teachers’ attitudes and perceptions related to practical work.
- To apply the questionnaire to a random sample of secondary teachers and provide data contributing to a characterization of teachers’ attitudes and perceptions on practical work.

## **METHODS AND SAMPLES**

This paper focuses on their characterization based on a transversal study. We consider the use of a questionnaire only as a mean to gather information and a resource which outcomes should be complemented with data from other sources (e. g. interviews, field notes, classroom observation).

We initially developed a self-report questionnaire containing Likert scale items grouped in sections to explore four aspects:

Section 1: purposes attributed to practical work (20 items)

Section 2: attitudes towards practical work (20 items)

Section 3: perceptions of engagement and control (21)

Section 4: subjective experience during implementation of practical work (36 items)

The following examples illustrate the nature of the items:



Table 1. Examples of items in each section

<b>Section 1: Purposes attributed to practical work</b>					
In science lessons, enquiry and practical activities intend that students...					
	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
Learn to use instruments or tools (e. g. a thermometer)					
Collaborate among them and work in groups.					
<b>Section 2: Attitudes towards practical work</b>					
	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
When doing practical activities, students ask things I do not know and make me feel uncomfortable.					
Practical activities work well if I prepared them well.					
<b>Section 3: Perceptions of engagement and control</b>					
	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
I only conduct the practical activities appearing in textbooks because I have no time to look for other ones.					
I have to conduct practical activities in my science classes, although I don't like them.					
<b>Section 4: Subjective experience</b>					
When I conduct enquiry and practical activities I feel...					
	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
Organized					
Dominant					
Stressed					

In the development and application of the questionnaire we followed these stages:

- I. Pilot study: elaboration of items, revision of items by external judges, initial application to a small intentional sample of teachers, items analysis, integration of the refined version of the questionnaire.
- II. Final application: To a random extended sample of teachers, items analysis (validity and reliability tests), response analysis, characterization of attitudes and practices related to practical work.

41 teachers were selected intentionally to participate in the pilot study. 102 teachers comprised the sample for the final application. Both groups of participants included female and male teachers aged 23-56, with 2 to 34 years of teaching experience; all were practicing secondary school science teachers working in state secondary schools. The first version of the questionnaire used in the pilot study included 96 items. The final version, after refinement, ended up with 100 items.

In the pilot study data analysis looked for statistical evidence on the discriminative power and internal consistency of the items, which could tell us about the validity and reliability of the questionnaire as a research instrument. For this purpose, t tests and Cronbach's Alpha coefficients were performed with SPSS v.14. Data coming from the final application was also processed statistically to confirm the validity and reliability of items, but the main analysis intended to identify patterns and tendencies in teachers' responses.

## RESULTS

The analysis of the pilot study data indicated that 84 of the initial 97 items had adequate discrimination power (t test,  $p < 0.05$ ); this indicated the need to refine 13 items. Regarding the internal consistency within each section, we obtained high and significant

Cronbach's alpha coefficients ( $p < 0.05$ ) for sections 1 (purposes) and 2 (attitudes) with all items being correlated and suggesting good internal consistency. For sections 3 (engagement and control) and 4 (subjective experience), coefficients were not significant and it was possible to identify 19 items with no correlation to their sections. Since both statistical tests pointed out problems with mostly the same items, we proceeded to review and refine them. Such review resulted in the eventual restructuring of sections 3 and 4. A second version of the questionnaire was trialled again with a sample of 20 teachers. This time we obtained satisfactory  $t$  values for each item and significant alpha coefficients for each section. These results gave us confidence in the use of the questionnaire as a research instrument.

In the final application, we ran the statistical tests for confirmatory purposes and found no significantly different results. Teachers tended to attribute as many cognitive as affective purposes to practical work which suggest that, as a group, they conceive that practical work is useful for almost any teaching purpose. Interestingly, they avoided to totally agree or disagree with items stating that practical work was useful to maintain the discipline in the classroom. 69% of teachers (71 out of 102) reported to hold positive attitudes towards the implementation of practical work. They expressed agreement with negative attitudes only in the case of two items related to the possibility that activities may not work or were likely to cause accidents. Although individually teachers differ significantly in their tendencies, an important number of them (79%) tended to perceive themselves engaged and in control when doing practical work. Similarly, in 71% of teachers the tendency was to report the experience of positive subjective experiences when implementing practical work as part of their teaching.

## CONCLUSIONS AND IMPLICATIONS

This study was focused on targeted aspects of teacher's attitudes and perceptions related to practical work. It can only provide a characterisation of the main features and tendencies within the sample or at an individual level. This information is useful in building a diagnostic description of how teachers are equipped to face curriculum demands concerning the implementation of practical work and associated aims. We followed the conventional procedure in the design and managed to develop a valid and reliable questionnaire, which is as a self-report instrument that privileges teachers' points of view. In order to make sense of these views, it would be important to explore them in conjunction with knowledge about teachers training background and conditions in schools for practical work. Other relevant aspects to incorporate in our diagnostic study include ongoing in-depth interviews to a subsample of teachers to explore the challenges and opportunities of using practical work to develop conceptual understanding and process skills. A more qualitative approach, like the dilemma discussions adopted by Hye-Gyoung & Mijung (2010) could be fruitful for such purpose.

The questionnaire, after trialling, pilot studies and consequent refinement, has proven to be a useful research instrument to identify general and individual tendencies. The initial tendencies identified in teachers' responses suggest good predisposition and benevolent attitudes in general; however these contrast with some teachers' lack of confidence and sense of control. Despite the sample size in the final application, we are not in the position to generalise the identified tendencies. Our initial characterisation of teachers' attitudes and perceptions will serve as a starting point for further research on effective ways of supporting teachers to develop skills and awareness on the potential and limitations of practical work. Some efforts should be oriented to develop awareness about distinctive teaching purposes and critical teacher interventions when implementing practical work with secondary school students.

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## WHAT STRANDS OF RESEARCH IN SECONDARY “NANO-EDUCATION”?

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*Abstract:* We present a review of literature that gives a snapshot of an emerging field in science education: “nano-education”, with a focus on secondary education. Our corpus was made of 20 articles from science education peer-reviewed journals and conference proceedings. We identified four strands of research: reflections prior to curriculum development on nanosciences and nanotechnologies; studies on students’ conceptualisations of nano-related concepts; use of haptic tools to teach nanosciences and nanotechnologies; and professional development for secondary school teachers. We also pointed the lack of research regarding nanosciences and nanotechnologies as a socioscientific issue.

*Keywords:* Nanotechnologies - Nanosciences - Secondary education - Nanoliteracy - Curriculum development

### BACKGROUND, FRAMEWORK AND PURPOSE

Since the launch of the National Nanotechnology Initiative by the US government in 2000, many countries have been investing in nanosciences and nanotechnologies developments. These investments are often accompanied by discourses laying emphasis on the interests to introduce nanosciences and nanotechnologies into the science curriculum (Roco, 2003) and also by funding to develop pedagogical materials as well as educational research on this topic. This is particularly pronounced in the US where the National Science Foundation has made many efforts to introduce nanosciences and nanotechnologies<sup>1</sup> in secondary schools’ classrooms and allotted many grants for research on “nano-education”. As a result, science education on nanosciences and nanotechnologies has been developing for a few years and this emerging field in science education may undergo important expansion in years to come.

We have worked on reviewing research literature in science education dealing with the introduction of “nanos” in secondary education (Hingant and Albe, 2010). Our purpose here is to give an insight into the directions in which science education research on nanosciences and nanotechnologies has been developing so far and has already produced results.

### RATIONALE

Many attempts have already been made to introduce nanosciences and nanotechnologies in secondary education in particular in the US. Accordingly, our aim was to provide an overview of this emerging field by reviewing literature to answer the following questions:

Which orientations of research about the introduction of nanosciences and nanotechnologies in secondary education have started to be explored?

Which results have already been yielded by these studies?

### METHODS

The words nanosciences and nanotechnologies refer to a vast collection of scientific and

technological research and developments involving nanometric objects. However actors involved in these developments do not agree on what deserve the tag “nano” and what is excluded from nanosciences and nanotechnologies. For our review, we left it to the authors to chose their own definitions of “nanos” and we only used articles whose authors claimed an interest for introducing nanosciences and nanotechnologies in secondary education. Accordingly, we chose the key words “nanoscience(s)”, “nanotechnology(ies)” and “nanoscale” along with “teaching” and “education” when searching articles. We gathered papers using ERIC database and reviewing papers from various English, French and US peer reviewed journals: *Science Education*, *International Journal of Science Education*, *Journal of Research in Science Teaching*, *Aster*, *Didaskalia*, *Journal of Science Education and Technology*, *Research in Science Education*, *International Journal of Science and Mathematics Education*, *American Educational Research Journal*, *Review of Educational Research*, *Educational Evaluation and Policy Analysis*, *Review of Research in Education*, *Journal of Curriculum Studies*, *Studies in Science Education*. We also visited selected Internet websites that led us to consult different conference proceedings (of the National Association for Research in Science Teaching conference and of the American Society for Engineering Education) as well as the *Journal of Nano Education* created in March 2009. We retained 20 documents, excluding from our corpus papers only depicting an innovation and lacking a sound theoretical framework.

## RESULTS

We identified four orientations of research. The first one is related to reflections prior to the design and implementation of a “nano-curriculum”. Studies have also been completed on the conceptualisation of some “nano-related” concepts. Some work deal with the use of some particular learning tools to teach students some nano-related concepts. We also encountered articles that were dealing with secondary school teachers' professional development on nanosciences and nanotechnologies.

### Reflections prior to the design and implementation of a “nano-curricula”

Among the questions preceding the design and implementation of nano-lessons we listed the following:

- Why to introduce “nanos” in secondary education and who is targeted?
- How to organise teaching nanosciences and nanotechnologies in secondary education?
- What concepts are considered prominent to understand the heterogeneous objects grouped together by the words nanosciences and nanotechnologies and how can these concepts be integrated in the science curriculum?

We identified two reported goals put forward to advocate the introduction of nanosciences and nanotechnologies in secondary education:

- To recruit the future “nano-workforce”;
- To provide citizens-in-the-making with tools to understand a world pervaded with nanotechnologies.

To introduce nano-contents, Schank, Krajcik, & Yunker, (2007) and Stevens et al., (2009b) emphasise the inherent interdisciplinarity of nanosciences and nanotechnologies. Stevens et al., (2009b) also underline the significance to take into account the existing constraints set by the educational systems. For their part, Schank et al. (2007) go further and consider that nanosciences and nanotechnologies provide an opportunity to profoundly reform the way science is taught in secondary education.

Finally concerning the concepts to be taught and deemed central to understand

nanosciences and nanotechnologies, the National Science Foundation funded workshops in 2006 and 2007 gathering educators and scientists to identify “big ideas” of nanosciences and nanotechnologies. This resulted in the identification of nine big ideas and their associated learning goals appropriate for secondary education (Stevens et al., 2009b):

1. Size and Scale
2. Structure of Matter
3. Force and Interactions
4. Quantum Effects
5. Size-Dependent Properties
6. Self-Assembly
7. Tools and Instrumentation
8. Models and Simulations
9. Science, Technology and Society.

### **Works on conceptualisation of “nano” related concepts**

Significant concepts to understand nanosciences have been targeted for example in the book “the big ideas of nanoscale science and engineering” (Stevens et al., 2009b) and empirical works have been completed on the conceptualisation of these notions:

- *on size and scale*: some works tend to show that people and in particular pupils encounter difficulties in apprehending small scales (Tretter, Jones, Andre, Negishi, & Minogue, 2006a; Tretter, Jones, & Minogue, 2006b). Tretter *et al.* (2006b) have also laid emphasis on the significance of direct experiences to conceptualise scales. Other authors have tried to understand how students develop their conceptions of size and scale and plan to use their findings to develop a learning progression on size and scale (Delgado, Stevens, Shin, Yunker, & Krajcik, 2007). They found that students' knowledge ranged from connected to entirely disconnected.

- *on the “nature of matter”*: having identified crucial concepts for the understanding of two constructs, atomic model and electrical forces, Stevens, Delgado, & Krajcik (2009a) have sought to develop two hypothetical learning progressions and striven to enhance the links between them. Their empirical study showed that students often did not perceive connections important to conceptual understanding.

- *on size dependent properties*: in an exploratory study, Taylor & Jones (2009) found there is a correlation between proportional reasoning ability and understanding surface area to volume relationships.

### **Works on the use of innovative tools to teach nano-related concepts**

Innovative learning tools have been used to teach nano-related concepts. In particular, some devices consisting in a haptic<sup>2</sup> interface coupled to an Atomic Force Microscope have been studied. The influence of haptic on learning and motivation has been investigated (Jones et al., 2004; Jones, Andre, Superfine, & Taylor, 2003). Results showed that using such devices has a positive impact on both students learning and engagement (Jones et al., 2004; Jones et al., 2003). In addition, results obtained by Jones et al. (2006) tend to indicate that the more sensitive the haptic tool is, the more efficient it proves in engaging students in activities and in supporting learning.

### **Studies on teachers’ professional development**

If nanosciences and nanotechnologies are to be integrated in the science curriculum,

teachers have sooner or later to be in charge of the teaching of these new contents. Consequently some works are taking an interest in secondary teachers' professional development. Some authors have described the hurdles which may dissuade teachers from integrating "nanos" into their lessons: difficulties to take into account interdisciplinarity, reluctance to deal with notions they have not been acquainted with during their initial training and on which they may be at a loss to answer pupils' questions (Schank et al., 2007). However, a few professional developments opportunities on nanosciences and nanotechnologies have already been offered to secondary school teachers and some have been studied in empirical works.

Tomasik et al. (2009) found that the learning environment used for their course met teachers' expectancies and that teachers chose to introduce nano-lessons throughout the year or as one bulk unit.

Bryan et al. (2007) noted that teachers came to a nano-summer school program mainly to learn nano contents and not about inquiry.

Concerning teacher's use of models for teaching nanotechnologies, it has been found that teachers view them as primarily useful for "show and tell" purposes (Bryan et al., 2007; Daly and Bryan, 2007)

Finally, Bryan et al. (2007), Daly et al. (2007), and Hutchinson et al. (2009) reported some difficulties encountered by teachers to implement nanosciences and nanotechnologies contents in their classrooms. Teachers have to locate where it could fit. Bryan et al. (2007), Daly et al. (2007), and Hutchinson et al. (2009) found that "nanos" were often added as extensions to pre-existing lessons. Hutchinson et al. (2009) also pointed out that teachers could lack time and confidence and also encounter technical difficulties to teach nano-lessons. Daly et al. (2007) and Hutchinson et al. (2009) also underlined that teachers sometimes had difficulties to cope with interdisciplinarity.

## CONCLUSIONS AND IMPLICATIONS

Our literature review provided four strands of research: reflections prior to the introduction of nano-lessons in the curriculum; studies on students' conceptualisations of nano-related concepts; use of innovative learning tools to teach nano-related concepts; and professional development for secondary school teachers. Thus, in the articles we vetted, we haven't found any studies regarding nanosciences and nanotechnologies as a socioscientific issue. However these developments raise controversies and among the "big ideas" deemed essential to grasp an understanding of nanoscale science and engineering the item "science, technology and society" was included (Stevens et al., 2009b). Consequently, to us, if nanosciences and nanotechnologies are to be introduced in secondary education so that every student could understand and participate in the debates surrounding these developments, the controversial dimensions of nanotechnologies also have to enter the classrooms.

## NOTES

1. In the United States, authors working on the introduction of nanosciences and nanotechnologies in secondary education often use the terminology "nanoscale science and engineering" (e.g.: Stevens, Sutherland, and Krajcik, 2009b).
2. A haptic tool is a tool rendering the sense of touch.

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## **SOURCES OF SCIENCE TEACHING SELF EFFICACY BELIEFS OF EXPERIENCED HIGH SCHOOL SCIENCE TEACHERS**

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*Abstract:* This ethnographic research aims to search for the sources of self-efficacy beliefs of experienced high school science teachers. Semi-structured formal interviews were made with three experienced science teachers (one biology, one chemistry and one physics teacher) who had experience over nine years of teaching. Results revealed that teachers' problem solving, teachers' making experiments and students' interest during lesson are sources of an increase in experienced science teachers' teaching science self efficacy beliefs. Outer factors related with students and class atmosphere are sources of a decrease in science teachers' teaching science self efficacy beliefs. Science teachers' mastery experiences especially the indirect, perlocutionary mastery experiences which include students' success and interest was found to be most highlighted source of teachers' science teaching self efficacy beliefs. Social/verbal persuasion is reported as a second effective source. Vicarious experiences and psychological and emotional arousal was mentioned by science teachers as not much effective for their teaching self efficacy beliefs. This study suggests that the great effect of mastery experiences on science teachers self efficacy beliefs would be analyzed deeply and might be separated into components and specific teaching activities for science teachers should be analyzed with respect to their effects on science teachers' more static and developed science teaching self efficacy beliefs.

*Keywords:* science teaching self efficacy beliefs, sources of self efficacy, experienced teachers, high school science.

### **BACKGROUND, FRAMEWORK, AND PURPOSE**

Bandura (1986, p. 391) defined self-efficacy beliefs as "People's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances". A teacher's self efficacy belief is so crucial because literature supports its consistent positive relationship with teacher behavior and student outcomes (Gibson & Dembo, 1984). Moreover, Ashton (1984) stated that "...no other teacher characteristic has demonstrated such a consistent relationship to student achievement" (p. 28).

A teacher's sense of efficacy may influence their emotive state, their goal setting and their persistence (Ashton and Webb, 1986). Denham and Michael(1981) found that there is some evidence to suggest that teacher attitudes influence teacher behaviours and that teacher behaviours influence student achievement. Research that is more recent has found that teacher self-efficacy beliefs strongly influence the nature of a teacher's role, planning, and, consequently, curriculum and student learning (Tobin, Tippins, and Gallard 1994). For, example, in science teaching, teachers with high self-efficacies were found to be more likely to use inquiry and student-centered teaching methods, while those with low self-efficacies were more likely to be teacher directed (Czerniak, 1990).

Research on science teachers' self efficacy beliefs is one of the growing trends among teacher education researchers recently. Science teaching efficacy is defined as a teacher's belief about his/her capability to teach science effectively and to affect student achievement

(Riggs, 1988). Science teaching efficacy belief has two dimensions in accordance with the Bandura's two sub-constructs within the conceptualization of self efficacy: personal science teaching efficacy beliefs (PSTE) and science teaching outcome expectancy beliefs (STOE). PSTE refers to a teacher's belief in his/her ability to perform required science teaching behaviors and STOE refers to the teachers' beliefs about the statement of "students can learn science given external factors such as their family background, socioeconomic status (SES), or school conditions" (Riggs, 1988, p. 20). As Bandura asserted, one's self efficacy is task or role specific and it can be changed according to situations. Therefore, teachers' self efficacy is examined under their subject area and its changing is examined for different conditions of teachers, that is, generally for pre-service and in-service conditions.

The usefulness of a high level self efficacy of teachers is obvious. However, the vital question here is "what are the sources of self efficacy?" Bandura (1997) defines four sources of efficacy building information: mastery experiences, vicarious experiences, social/verbal persuasion and psychological and emotional arousal. Determining specifically the sources of teachers' self efficacy in their subject area teaching would be helpful for teacher training or assisting teachers in schools and for developing self efficacy scales for science teachers.

This study aims to answer three main questions revolving around sources of experienced science teachers' self efficacy beliefs. These are:

1. What types of experiences are considered by experienced science teachers as effective for increasing their science teaching self efficacy beliefs?
2. What types of experiences are considered by experienced science teachers as effective for decreasing their science teaching self efficacy beliefs?
3. How are experienced science teachers' self efficacy beliefs linked to Bandura's four sources of self efficacy beliefs?

## **RATIONALE**

Dembo and Gibson (1985) stated that "The problem of identifying antecedents of efficacy and developing ways to enhance teachers' sense of efficacy is critical...researchers must consider many variables as well as the complex manner in which they interact" (p.177). There is a great mount of researches about self efficacy of pre service teachers. Self efficacy of in service teachers is a less searched area than of pre service teachers. In fact, a more developed, and more static self efficacy of experienced teachers is need to be searched in order to understand what pre service teachers are going to face with in their following years and also as Ramey-Gassert, Shroyer and Staver (1996) stated, to understand how to motivate teachers to teach science.

Based on the theoretical implications and literature evidence of positive effects of self efficacy in affecting teacher behavior, this ethnographic research aims to search for the sources of self-efficacy beliefs of experienced high school science teachers. In the literature studies about elementary school science teachers' self efficacy beliefs are dominant and hence studies for high school science teachers' science teaching self efficacy beliefs is a bigger gap today. Determining specifically the sources of high school science teachers' science teaching self efficacy beliefs would be helpful for teacher training and assisting science teachers in high schools and for developing self efficacy scales for high school science teachers.

## **METHODS**

Semi-structured formal interviews were made with three experienced science teachers (one biology, one chemistry and one physics teacher). Three science teachers who were female and had experience over nine years of teaching were chosen purposively. Interviews

were recorded by audiotape and transcribed in documents. At the beginning of the interviews, an introduction and basic interview guidelines were presented to the teachers. To provide clearness of the terms “self efficacy” and “teaching self efficacy” for teachers during the interview, the explanation of the terms in Turkish, which are provided by academic studies, were both given the teachers in a written paper and explained by the researcher orally. Also, researcher asked to the teachers whether they understood them. Interviews began after researcher was convinced that teachers grasped the terms. Teachers were told that they were going to be asked a series of questions related with teaching self efficacy.

The questions of the interview are prepared by examining the self efficacy tests in the literature. Some items in the tests are turned into question form. There are three parts in the interview. After getting the general information about teachers in the first part, questions about vocational thoughts were asked in the second part. Then for the final part, questions about “how efficacy is influenced and what influences efficacy” were asked. Two listed item questions were asked. These two questions were developed by taking views and answers of other three experienced teachers to the question of “what makes you feel more efficacious in teaching?” The defined items are listed and asked to interviewees to give points from 1 to 5, to show its impact on that feeling of teaching self efficacy.

Finally, the data were grouped and analyzed with clustering technique (Miles & Huberman, 1984) with respect to answering the two main questions of the research.

## RESULTS

Results are presented under headings of the three main questions of the study. But before seeing separate and somewhat different views of the teachers, it would be meaningful to give their some personal characteristics.

### Profiles of Teachers

Biology teacher: She was 30 years old. She had 9 full years of teaching experience and a master degree in biology. She had taught in university entrance examination preparation courses for 7 years and then she had been teaching in a private school for two years. She said that she had had a great interest in biology and so chose to be a biology teacher. She defined herself as curious and effortful towards science and hence loved her job; teaching. It is noticeable that biology teacher linked the attitude towards science and loving to teach. She answered as “yes” when interviewer asked her whether she saw herself as a successful teacher and she immediately continued by adding “it isn’t a self conceit, right?” In Turkish culture it is commonly accepted as discreditable for someone to praise herself/himself and this biology teacher was so certain about her goodness in teaching such that she worried to assert this explicitly.

The strengths and weaknesses in teaching profession were asked to teachers. Biology teacher said that due to long time she had spent in university entrance preparation courses she was good at those subjects asked in UEE (university entrance examination) and making students study –in UEE courses students are scheduled to study and solve necessary number of tests about exam subject and they are controlled by teachers periodically. Hence, an important role of teachers in those courses is to make students study and to control their plan, in other words, to help students self regulate studying-. She explained her vocational weaknesses as making experiments, fieldtrips and observation. Moreover she explained that those weaknesses were due to her insufficient experience in school teaching and she added that she needed development in those school activities.

Chemistry teacher: She was 35 years old. She had 14 full years of teaching experience and in last two years of her teaching she was also an administrative staff in her school. She said that the reason of her choice to be a chemistry teacher was that she had loved her chemistry teacher much in high school. She defined herself as “not a very good teacher but a little above the middling good teachers”. When interviewer asked her whether she saw herself as a successful teacher she said “not much, I think”.

Chemistry teacher criticized herself about not spending much time on her professional development and mentioned it as a weakness in her profession. She explained her weakness such that she would have solved much more chemistry problems and would have finished various test books and she would have made experiments alone in laboratory. She mentioned her good lecturing as strength in her teaching profession.

Physics teacher: She was 37 years old and had 16 full years of teaching experience in high schools. She stated her reason of choice to be a physics teacher as her bad physics teacher in high school. The interviewer conceived that this choice was a reaction to interviewee's suffering in her studentship and hence she had wanted to show a better performance in physics teaching than her bad teacher had shown in the past. She defined herself as a teacher who was trying to have close relationship with her students emotionally and trying to understand them. Moreover she explained the principle of her behavior by saying “in order for students to love the lesson they must first love the teacher”.

When interviewer asked her whether she saw herself as a successful teacher she said that her success depends on classes. In Turkey, in most schools, classes are formed by ability grouping and so meaning of classes in her explanation is success levels of students. She also explained classes' effect by saying that in good classes her success was better and in bad classes she was trying to help students as much as possible. Physics teacher asserted her deficiencies in classroom management as a weakness and asserted her good subject matter knowledge as strength in her profession.

### **Increase in science teaching self efficacy beliefs**

According to biology teacher solving many problems about subjects increases her science teaching self efficacy beliefs mostly. Chemistry teacher also supported this by exemplifying as skimming and solving problems in different test books. Physics teacher did not say something explicitly about the effect of solving problems on her self efficacy beliefs, however when the instructional activities were asked to put in an order from most to least affective on her teaching self efficacy she put solving problems in the second place.

The other thing that all three science teachers mentioned about its effect on their teaching self efficacy is the interest that students exhibit to the lesson. Biology teacher gave examples of signs that indicate students' interest for the lesson: students' listening to lesson carefully, their participation by asking questions and problems that they could not solve, their note taking, their smiling when teacher changes her tone of voice and students' oral statements about their grasp.

All three teachers supported that making experiments would affect their teaching self efficacy. What is more all of them put *making experiments* on the first place among instructional activities that affect teachers' science teaching self efficacy. It is worthy that all three science teachers put the instructional activities in the same order with respect to their effects on their science teaching self efficacy. The order was like that: 1. *Making experiments*, 2. *Solving problems*, 3. *Answering questions that students ask*, 4. *Concept Instruction*.

The first research question of the study was that “what types of experiences are considered by experienced science teachers as effective for increasing their science teaching self efficacy beliefs? Results of this study provide an answer for this question like that: teachers’ problem solving, teachers’ making experiments and students’ interest during lesson are sources of an increase in experienced science teachers’ teaching science self efficacy beliefs.

### **Decrease in science teaching self efficacy beliefs**

The reverse of the things that teachers told as increasing their teaching self efficacy is also valid for decreasing it obviously. However, in this section the things that teachers especially mentioned about their negative effect on their teaching self efficacy beliefs are written.

The things that would affect teaching self efficacy negatively for biology teacher were getting a poor score from the examination for teachers –in the private school she worked there were teacher exams for all branches each year-, not getting feedback from students during instruction, not solving more tests and problems and a consensus occurred in the class about not understanding the subject. For chemistry teacher the naughty students who did not progress positively after help, not spending enough time on her professional development-by making experiments in the laboratory- were the things that would increase her teaching self efficacy. According to physics teacher students’ being uninterested, unwilling and not having enough previous knowledge for the subjects would increase her teaching self efficacy beliefs.

The second research question of the study was that “what types of experiences are considered by experienced science teachers as effective for decreasing their science teaching self efficacy beliefs?” The gathered answer for this question from the study is that a consensus occurred in the class about not understanding the subject, uninterested and unwilling students, students not having enough previous knowledge for learning new subjects, problematic students who did not progress after help and bad class atmosphere are sources of a decrease in science teachers’ teaching science self efficacy beliefs.

### **Links to Bandura’s four sources of self efficacy beliefs**

The third and last research question of the study was that “how are experienced science teachers’ self efficacy beliefs linked to Bandura’s four sources of self efficacy beliefs?” Gathered results are summarized according to their links to four sources of self efficacy (mastery experiences, vicarious experiences, social/verbal persuasion and psychological and emotional arousal) that are defined by Bandura (1997).

Mastery experiences are mentioned to be most effective by science teachers for their self efficacy beliefs, and this is consistent with what Bandura asserted about effect of mastery experiences on self efficacy beliefs (1997). Getting a high score in teachers’ examination, solving problems and making experiments are mastery experiences that teachers explained that they affect their teaching self efficacy beliefs. However teachers gave more explanations about the effect of students’ achievement, interest and participation to the lesson on their teaching self efficacy beliefs. Moreover, although it is obvious that mastery experience of teaching the subject for years is one of the major source of teaching self efficacy of teachers however, it is not mentioned by teachers in this study maybe due to they are all experienced teachers and do not have concerns about their enduring teaching skills.

Teachers especially mentioned that verbal persuasions are not much affective whereas social persuasions such as students' consensus on teacher effectiveness will be very effective on their teaching self efficacy beliefs. According to teachers, students' empty compliments will not be affective but their sincere views and statements about learning by instruction of teacher will be affective. Verbal persuasions of administrative staff and other teachers are mentioned as weakly affective for their teaching self efficacy beliefs.

The least affective source of teaching self efficacy beliefs for science teachers was vicarious experiences. All three teachers asserted that they seldom compare their selves with other teachers. According to chemistry teacher and physics teacher this would happen only when they see or hear that other teachers use a new instructional tool or strategy effectively. In that case, teachers indicated that they would try to learn and apply the new thing that other teachers do. Biology teacher said that enthusiasm of another teacher might affect her teaching performance positively.

Psychological and emotional arousal does not seem to be affective for science teachers self efficacy beliefs. Only physics teacher said that sometimes negative events she faced in her daily personal life would decrease her teaching self efficacy beliefs. But, she highlighted that she was trying to eliminate the positive effects of those personal life events and succeeded at that at ninety percent.

Other source of teaching self efficacy beliefs of science teachers would be outer conditions which are generally temporary and under not control of teachers. For example, physics teacher and chemistry indicated that students' previous knowledge that are necessary for learning new subject is very important for themselves to feel their selves efficacious on teaching this new subject. Physics teacher also pointed out that class atmosphere is very important, that is when class' academic level is high she feels herself more successful or vice versa. Biology teacher talked about class atmosphere too. Lastly all three science teachers mentioned about the difficulty of the subject matter as affective on their teaching self efficacy. Some topics in their branches are more difficult than others and they feel less efficacious on teaching these difficult topics due to concerns about students' understanding.

## CONCLUSIONS AND IMPLICATIONS

Mastery experiences were mentioned to be most effective by science teachers for their self efficacy beliefs however; mastery experiences might be separated as personal and perlocutionary mastery experiences for teachers. Perlocutionary means "an act of speaking or writing which has an action as its aim but which in itself does not effect or constitute the action, for example persuading or convincing" (seslisozluk). Getting a high score in teachers' examination, solving problems and making experiments are teachers' personal mastery experiences that affect their teaching self efficacy beliefs. On the other hand students' achievement, their interest and participation to the lesson are teachers' perlocutionary mastery experiences that affect their teaching self efficacy beliefs. In fact perlocutionary mastery experiences of teachers might be more important for teachers self efficacy beliefs than their personal mastery experiences since three teachers in that study gave fifty percent and above weight for their effect on students' success when it was asked. Students' reactions and success are important indicators of teachers' teaching success, i.e. mastery experiences.

Social/verbal persuasion effect on teaching self efficacy of science teachers can be divided as social persuasion and verbal persuasion because teachers especially mentioned that verbal persuasions were not much effective whereas social persuasions such as students'

consensus on teacher effectiveness would be very effective on their teaching self efficacy beliefs.

In brief, the great effect of mastery experiences -both revealed in the results of this study and in the literature- on science teachers self efficacy beliefs would be analyzed deeply and might be separated into components such as personal mastery and perlocutionary mastery experiences and specific teaching activities for science teachers should be analyzed with respect to their probable and plausible effects on science teachers' more static and developed science teaching self efficacy beliefs.

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# THE COMPLEX ROAD TO MATHEMATIZATION IN PHYSICS INSTRUCTION

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**Abstract:** How to facilitate students' understanding of science's abstract concepts is definitely a major concern of every dedicated physics teacher. However, discussions about promising ways to be successful at this task are not always part of teacher training curricula. With the goal of contributing to the research in this field, we have analysed a set of lectures given by a distinguished physics professor. In this proposal we present the analysis of two lectures where the abstract concepts of charge density and electric flux are taught. The complexity of the mathematization of these concepts is evident both by the considerable amount of time dedicated to it and by the different strategies used by the professor in his exposition. These strategies are described and exemplified. Using the software *videograph* for the video analysis, we were able to identify the specific instants where each strategy takes place as well as their duration and interplay. This dynamical process is visualised with the aid of a timeline generated by the program. In general, our analysis evidenced that the professor adopted a "concrete to abstract" approach, made an extensive use of visual representations and concrete analogies, mentioned idealizations explicitly and made punctual metacognitive remarks. Taking into account the future perspectives of our research, the categorization of the didactical strategies used by this professor shall allow us to develop comparative studies with other lectures on the same topic. Moreover, the derivation of promising strategies to teach the structural role of mathematics in teacher training courses is also aimed at by this research.

**Keywords:** Mathematics in physics instruction, video analysis, mathematization complexity, structural skills.

## INTRODUCTION

Physics and mathematics are deeply interrelated since the very origin of scientific knowledge and this mutual influence has played an essential role on both their developments (Bochner, 1981; Gingras, 2001, amongst many others). Mathematical concepts being motivated by physical problems can be found, for instance, at the origin of calculus and its relation to the study of movement or at the development of vector analysis and the need for a mathematization of electromagnetic phenomena. From the physics perspective, mathematical concepts created in an "abstract world" are commonly "applied" by physicists to build their theoretical explanations. The use of conic sections in Kepler's astronomy or of complex numbers in Fresnel's optics are some among many other examples. More recently, this mutual interplay has reached a higher level where the very physical concepts "cannot be divided into a mathematical part and a non-mathematical one" (Boniole & Budinich, 2005, p. 86).

But what are the implications of this successful relationship for physics education? Despite the significant amount of research on how to improve students' conceptual understanding of physics, works focusing on building a meaningful comprehension of the role of mathematics in physics education are considerably less common. Hestenes (2003, p. 104) raises attention to this fact when he states that "the challenge is to seriously consider

the design and use of mathematics as an important subject for physics education research”.

A quite widespread view regarding this theme is that mathematical skills are prerequisites for learning physics. However, it seems that the domain of these skills is far from being a guarantee of success (Hudson & McIntire, 1977). Previous research about students’ use of mathematics to solve physics problems (Tuminaro & Redish, 2007) has already shown that rote application of formulas without physical reasoning is a rather common strategy. It has also been demonstrated that students face a huge difficulty when they need to transfer knowledge between mathematics and physics (Basson, 2002). It is fairly reasonable to expect that this difficulty is related to instruction methods, but works approaching this field from a teaching perspective are even less frequent.

With the goal of contributing to close this gap, our research is concentrated on the analysis of mathematical reasoning in physics lectures. The ability to use mathematics in physics is divided between *technical skills* - the ones related to the domain of basic rules of mathematics and normally developed in math’s classes - and *structural skills* - which are related to the capacity of recognizing the structural role of mathematics in physical thought [1]. Among the latter, the extreme complexity of *mathematization* - translation between the physical world and mathematics - and the main role it played in the lectures from our data demanded a deeper analysis. Even though fostering students’ understanding of science’s abstract concepts is a major concern of every dedicated physics teacher, promising ways to be successful at this task are not always available. Therefore, in this work we address the following questions: Which strategies are used by an experienced professor to teach the mathematization of the physical concepts of charge density and electric flux? How does the interplay between these strategies take place during the lectures?

## METHODS

Aiming at a deeper investigation of the mathematical reasoning in physics instruction, we decided to conduct a case-study at university level. We chose to analyze the lectures of a particular professor from the University of São Paulo for he is widely acknowledged as an excellent lecturer, since he constantly encourages his students to reason about the physical meaning of the mathematical formalism. In this sense, we started from the hypothesis that his approach would focus on the structural role of mathematics instead of its technical aspect.

Our data consist of the recordings of 40 lectures (total of approximately 60 hours of video) from a course on Electromagnetism. Initially, we watched the lectures directing our attention to the moments where mathematical reasoning took part in the exposition. More specifically, we concentrated both on the explanation of fundamental concepts that are expressed mathematically (e.g. each one of Maxwell’s equations) and on problem solving moments.

Afterwards, we chose some lectures for deeper analysis with respect to the identified *structural skills*. For video analysis we used the software *videograph*, divided the lectures in 20-second intervals and categorized each of them. In this work, we present the analysis of two lectures in which the structural skill *mathematizing* plays the central role. The content is the introduction of the rather abstract concepts of charge density and electric flux. The complexity of this process is highlighted by the description of different strategies used by the professor and by the image of a timeline where their frequency and interplay can be evidenced.

## RESULTS

The following table presents the set of categories that appear more often in the analysis of the two lectures presented in this work. The main goal of both lectures is to *mathematize* the concepts of charge density and electric flux.





Category	Description	Examples from the lectures
Mathematizing  M3 Just/Comp. M2 Math Struct. M1 Modeling	The process of mathematization occurs in a gradual way. Initially, the professor makes an extensive use of concrete representations and clarifies the idealizations imposed by the theoretical model. Then, mathematical structures are used to represent physical quantities and their relations. Normally, justifications for the use of certain structures and comparisons between different mathematical representations are presented and discussed.	<i>"This page is not bi-dimensional, but I think of it as if it were"</i> M1 <i>"We normally use Cartesian or polar coordinates to think about the two-dimensional situations"</i> M2 <i>"We use polar coordinates because the situation is symmetric"</i> M3
Visual representations  V2 Pictorial V1 Gestural	Along the process of constructing mathematical representations of the physical concepts of charge density and electric flux, the professor makes use of several visual representations. More specifically, many drawings are made and his language is extremely gestural.	<i>"This is theta (points at the door) this is theta plus d theta (opens the door)"</i> V1
Analogy  A2 Formal A1 Material	Analogical reasoning is extensively used during the lectures. Everyday life examples and material analogies with other physical phenomena have a powerful role in the construction of the physical concepts of charge density and electric flux. Moreover, catching attention to formal similarities is also a common strategy.	<i>"How can we describe the population density of our country?"</i> A1 <i>"They took this mathematical formulation to use in many other cases [...] But there are important differences"</i> A2
Metacognition 	Metacognition is the knowledge and awareness of one's own cognitive processes and the ability to monitor, regulate and evaluate one's thinking. The professor frequently encourages his students to think about their own thinking during the lectures.	<i>"His question is very good. It indicates confusion, but this always occurs with everyone who studies this thing. If it did not occur with you, it's because you didn't realize it yet"</i>

Table 1: Description of the most common strategies used by the professor to mathematize the physical concepts of charge density and electric flux with examples from the two analysed lectures.

### Charge density lecture

The following timeline (Fig. 1) - created with the software *videograph* - is a visual representation of a lecture on charge density. It provides an insight to the dynamics of the explanation process that took place during the lecture.

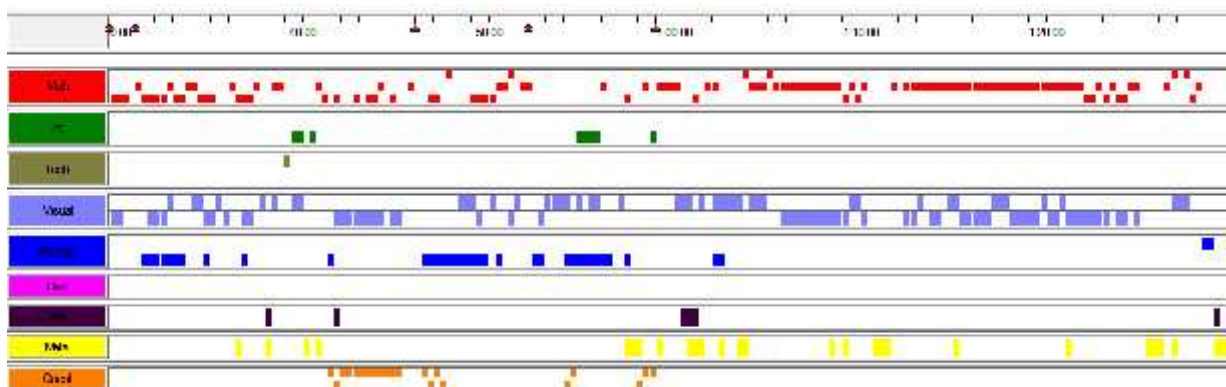


Figure 1: Timeline containing 60 minutes of the charge density lecture. Description of the categories from bottom to top: Quest - Dialogues between the professor and the students; Meta - Metacognitive remarks. Phi - Philosophical comments; Ded - Mention to deductive aspects; Analogy - Everyday life examples, material analogies with other physical concepts and formal similarities between different physical phenomena; Visual representations – gestural and pictorial; Tech - technical manipulations; Int - Interpreting mathematical expressions physically; Math - Translation between the physical world and mathematics.

This timeline allows us to identify the importance of each strategy used by the professor as well as the time dedicated to them. It is clear that visual representations (light blue) play an important role to make the abstract idea of charge density more intelligible. An intensive use of gestures is detected, for example, when the professor explains three different coordinate systems to describe volumetric charge density with the aid of a box and the classroom door. Several pictorial representations, as well as concrete analogies (dark blue), are employed as sources of explanation for the introduction of each different case of charge density (linear, surface and volume).

It is also possible to notice that the idealization process and the use of mathematical structures are highly important due to the time dedicated to them (red). By watching the lecture, one realizes that the professor makes an effort to mention them explicitly. The frequent shift from concrete representations to idealizations is also noticeable and metacognitive remarks (yellow) are frequent along the whole lecture. In the end, a longer moment of justification takes place as if the reasons why the students should learn the mathematical description of charge density are being summarized.

The following transcripts from the professor's discourse and their corresponding categorization complement the described analysis:

32:00	Imagine that you are all point charges and I want to calculate the net field at the position where I am. (A1, V1)
1:00:20	This (reference of frame) is a reasoning instrument, it is not in nature, but in your mind. It is an invention. (Met, Phi)
1:09:20	That is actually not a square, but if everything is very small, then it is useful to make this approximation. (M1, V2)
1:29:00	Today we learned some strategies to deal with distributions of things. This is very general, it can be with charge, mass, population, anything that needs to be distributed. Cosmology, stars, galaxies, Parsec, all [...] This makes sense and this is the way we think. (A2, Met)

## Electric flux lecture

In the analysis of the electric flux lecture, we notice a similar pattern, which is illustrated by the timeline presented at figure 2.

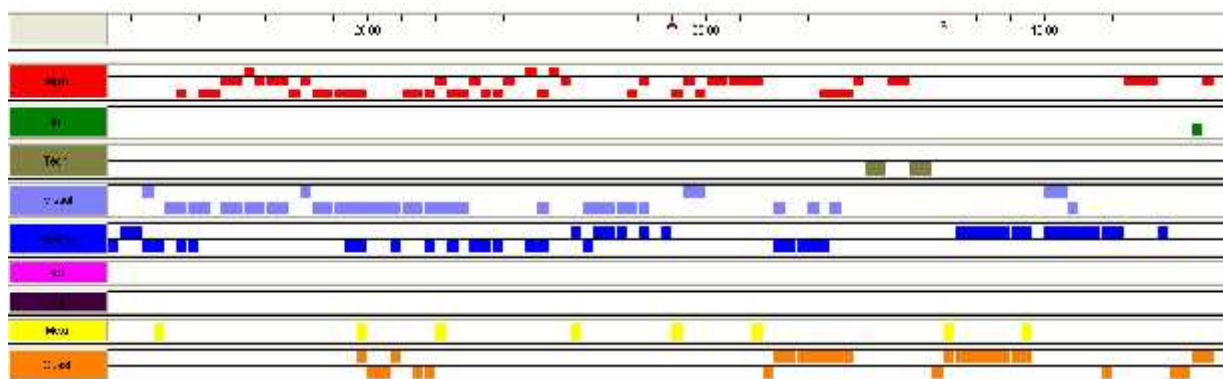


Figure 2: Timeline containing 32 minutes of the electric flux lecture.

The professor starts this lecture with different physical phenomena where the notion of flux applies, mentioning everyday life examples and using several analogies. Then, each relevant variable that influences this magnitude is mentioned and discussed with the students. Once

again, we notice that visual representations (especially gestures) are extremely useful for the explanation of the concept.

Instead of just giving the mathematical formula of the flux of a vector field through a surface, the professor presents its mathematical structures (dot product and surface integral) as reasonable for the description of the flux concept. Moreover, although many different phenomena are mentioned, explicit remarks about important differences between them (e.g. the electric and gravitational flux have no velocity) are explicitly stated.

The following transcripts from the professor's discourse and their corresponding categorization complement the described analysis:

- |       |  |
|-------|--|
| 18:20 | We speak about flux through a surface. [...] If the direction of the normal to the surface varies, the flux also changes. (M1, V1)   |
| 26:00 | Then we define flux by the surface integral of the projection, scalar product, between the vector I'm considering and the normal to the surface. (M2)  |
| 37:20 | His question is very good. It indicates a confusion, but this always occurs with everyone who study this thing. If it did not occur with you, it's because you didn't realize it yet. It is occurring and you are not aware of that. (Met)   |
| 39:40 | Every time you work in hydrodynamics – bees, water air – the flux represents something that passes through a surface. They took this mathematical formulation to use in many other cases [...] But there are important differences. The gravitational field doesn't really flow, it doesn't have any velocity. It is there. (A2) |

## CONCLUSIONS AND PERSPECTIVES

When a physics teacher simply states the formula that describes a particular physical phenomenon and then uses it to solve standard problems he/she is actually making an enormous conceptual jump. In reality, he/she is usually underestimating the complex process of mathematization. A brief overview of the history of physics is sufficient to illustrate that the mathematization of this science was a long and complicated process (Bochner, 1981).

In this paper we aimed at stressing the complexity of the translation between the physical world and mathematics by analysing physics lectures on the concepts of charge density and electric flux given by a special professor. The central role of mathematization became evident due to the considerable amount of time dedicated to it. Essentially, this analysis evidenced the following strategies: a *from concrete to abstract* approach, an extensive use of visual representations and material analogies, explicit remarks on idealizations and metacognitive comments. It is not our intention to suggest that this should be followed as a “*how to*” guide, however we strongly believe that these results underline several obstacles of the complex road to mathematization, which should be taken into account in physics lessons.

As future perspectives of this research we intend to investigate other lectures - from this professor as well as from others - and compare their different patterns with the same analytical tool. An additional possibility is to investigate how similar themes are presented in didactical classics like Feynman lectures. With this work we envisage to derive promising strategies to teach the structural role of mathematics with the goal of including such discussions in physics teacher training courses.

## NOTES

1. For a deeper discussion about this distinction see Uhden, Karam, Pietrocola and Pospiech (2011).

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# **ELEMENTARY TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE AND STUDENT ACHIEVEMENT IN SCIENCE EDUCATION**

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*Abstract:* The scope of this paper is to explore whether elementary science teachers' pedagogical content knowledge (PCK) in the content area "states of matter and changes of state" contributes to gains in elementary students' understanding of related concepts. The paper reports on a value-added study with a sample of 60 fourth-grade classrooms and their science teachers. The data derived from a project funded by the German Research Foundation (project "PLUS"). Teachers' PCK and student achievement concerning the mentioned scientific topic were directly assessed with tests. Multilevel regression analyses were conducted to analyze the significance of teachers' PCK for students' progress in elementary science classrooms. Results showed that teachers' PCK was significantly related to student achievement in elementary science after controlling for key student- and teacher-level covariates.

*Keywords:* teachers, pedagogical content knowledge, student outcomes, science education, hierarchical modeling

## **INTRODUCTION**

In the research literature on teaching and teacher education, there is a shared understanding that teachers' professional knowledge is an important determinant of instructional quality that impacts students' achievement gains (Baumert & Kunter, 2006; Bromme, 1997; Munby, Russell, & Martin, 2001). Yet few empirical studies have assessed the different components of teachers' knowledge directly and separately to predict instructional quality or student outcome. The main goal of this study was to explore whether teachers' pedagogical content knowledge as a crucial component of teachers' professional knowledge makes a contribution to explaining differences in students' learning outcomes in elementary science education.

The study is part of the project PLUS (Teachers' professional knowledge, science teaching and student outcomes in the transition from primary to secondary school) that investigates conditions and outcomes of science instruction in the transition from elementary to secondary education. It was conducted in Germany from 2007 to 2010. The study, which had two measurement points, surveyed a sample of 60 elementary science classes and 54 secondary science classes and their teachers. Drawing on the elementary sample, the study at hand explored whether teachers' pedagogical content knowledge in science contributes to gains in students' understanding of scientific concepts. In order to address this question we used a newly constructed knowledge test to assess teachers' pedagogical content knowledge in the domain of science directly. Teacher data was then linked to data on student outcome, in order to determine the implications of pedagogical content knowledge for student learning.

## RATIONALE

The theoretical foundation of research on teachers' professional knowledge was laid at the American Educational Research Association meeting in 1985, when Lee Shulman proposed a model for conceptualizing knowledge for teaching. There he introduced the constructs of generic pedagogical knowledge, content knowledge and pedagogical content knowledge as the core components of the specialized knowledge that is required for teaching. Although researchers have added to or specified these domains of teacher knowledge over the last decades, these three components have consistently appeared in literature and thus seem to be internationally agreed upon as core components of teachers' professional knowledge (Baumert & Kunter, 2006; Borko & Putnam, 1996; Bromme, 1997; Munby, Russell, & Martin, 2001). Knowledge of generic pedagogy (PK) is described as general, subject-independent knowledge about classroom organization and management, general knowledge of learning theory and general methods of teaching. Content knowledge (CK) includes the knowledge of a subject or discipline per se and is not unique to teaching. It goes beyond the knowledge of facts, concepts, principles and theories to also include an understanding of how concepts and principles of a subject are organized and the rules of evidence and proof that are used to justify claims in a certain subject or discipline. Within this classification of teachers' knowledge, pedagogical content knowledge (PCK) is considered the central component of teachers' professional knowledge that distinguishes teachers from subject matter specialists (Grossman, 1990; Shulman, 1987; Van Driel, Verloop, & De Vos, 1998). PCK is defined as a kind of "amalgam" of content knowledge with pedagogical and psychological knowledge as well as with the teachers' personal experiences, creating an understanding of how certain topics, problems or issues ought to be presented and adapted to the learners' different interests and abilities (Shulman, 1987). Magnusson, Krajcik and Borko (1999) proposed a model of PCK in the area of science education, defining five components. They include 'orientations towards science teaching', 'knowledge of science curricula', 'knowledge of students' understanding of science', 'knowledge of instructional strategies' and 'knowledge of assessment for science'. Recent studies on the different domains of PCK (e.g. orientations towards teaching, knowledge of students' understanding or instructional strategies) in mathematics found that teachers' mathematical PCK was positively related to students' gains in mathematical achievement (e.g. Staub & Stern, 2002; Hill, Rowan, & Ball, 2005; Baumert et al., 2010). Whereas studies in the domain of orientations towards teaching have already been established in the field of elementary science (Kleickmann, 2008), studies targeting at the further components of PCK are missing completely in elementary science. Thus, this study aims at measuring elementary science teachers' PCK directly, followed by examining its relevance for students' gains in conceptual understanding.

## METHODS

Comprising 1326 fourth-graders (621 girls and 702 boys, 3 students did not indicate gender) in 60 classrooms, the data presented here stems from a project investigating the development and interplay of science instruction, classroom climate and students' science interest in the transition from primary to secondary education in Germany (PLUS Study). The cross-sectional study had a quasi-experimental design. Participating teachers were instructed to provide their classes with a series of three 90-minute lessons on the topic of evaporation and condensation. Students were tested for science achievement concerning the topic "states of matter and changes of state" both



before and after the series of lessons. Teacher data were gathered from various instruments amongst others a test assessing their PCK in the domain of “states of matter”.

The assessment of teachers’ PCK was based on the Magnusson et al. model (1999). Considering the recent studies in mathematics that described ‘knowledge of students’ understanding’ (KSU) and ‘knowledge of instructional strategies’ (KIS) as components of PCK that trigger students’ achievement, the focus of the test was nested within these two components. The developed items asked teachers e.g. to list as many alternative students’ conceptions as possible concerning an every-day evaporation situation (KSU). Other items presented situations in which teachers are asked to detect comprehension difficulties or to describe adequate behavior to promote insightful student learning (KIS). The final test consisted of 14 items (11 free-response-, 3 multiple-choice-items) and showed good psychometrical qualities (average ICC= .92, range: .8 - 1.0; Cronbachs  $\alpha$  = 0.69).

Student achievement was assessed at the end of the unit by a test covering condensation and evaporation as well as the liquid and gaseous state of matter (using water as example). The reliability of the full test (24 items in *multiple-choice-* or *multiple-select-format*) was Cronbachs  $\alpha$  = .67 in the pretest and Cronbachs  $\alpha$  = .79 in the posttest.

Multilevel analyses were used to analyze the impact of elementary science teachers’ PCK on students’ gains in conceptual understanding. A two-level model predicting the achievement on the posttest-score on the individual-level by teachers topic-specific PCK on the class level was specified. To account for other important predictors, we controlled for relevant student characteristic like prior knowledge, general cognitive abilities, German as native language, socio-economic background and gender as well as for critical classroom and teacher characteristics like duration of instruction, classroom-management and job experience. To account for missing data we used the full information maximum likelihood algorithm implemented in the software Mplus, which estimates the missing values (Muthén & Muthén, 1998-2009).

## RESULTS

In a first step, the variance in students’ achievement was decomposed into within- and between-class components. The results showed that 78.6% of the variation in achievement was within classes and that 21.4% was between classes. After controlling for the variables at the individual level, 14.4% of the variation in achievement remained between classes.

In a second step, we specified the individual model. We estimated a random intercept model with the five control variables named above. The most important predictor was that of students’ topic-specific prior knowledge at the beginning of the unit, followed by general cognitive ability. Beyond that, German as native language, socio-economic background and gender proved to be less important.

In the next step, the control variables at the class level were entered in the model. The predictors at class level were: duration of instruction, quality of classroom-management and job experience. All variables proved to be significant predictors of students’ learning achievement concerning “states of matter” at the end of the unit.

When PCK of elementary science teachers was entered in the model next to the control variables the results revealed a substantial positive effect of the measured PCK on students’ gains in

science achievement in the domain of “states of matter”. Thirteen percent of the variance in achievement between classes was explained by PCK after controlling for key student- and teacher-level covariates (for detailed analyses see Lange, Kleickmann, Tröbst, & Möller, in print).

## DISCUSSION AND CONCLUSION

In the presented study we constructed and implemented a test to assess primary teachers’ PCK directly. In sum first analyses indicate that we succeeded in developing a reliable and valid test which was needed to answer our research questions on the impact of PCK on students’ achievement gains in elementary science classrooms. When controlling for several predictors at individual and class level, we were able to show that elementary science teachers’ PCK positively predicts students’ gains in science achievement in the domain of “states of matter”. These results are nicely in line with findings on effects of domain-specific knowledge in the field of mathematics (Baumert et al., 2010, Hill et al., 2005).

Compared to the effect sizes found in the studies in the domain of mathematics the effect sizes are rather small. It could be argued that this is a domain-specific effect. On the other hand the small effect size could be explained by the short treatment-duration of the study conducted. While the studies in the field of mathematics investigated the impact of teachers’ PCK on students’ learning gains over a whole school year, our study chose a topic-specific approach. Focusing on just one content area, we investigated the impact of teachers’ PCK on student achievement over an average treatment duration of approx. seven lessons. Against this background, the question whether the small effect size is a domain-specific effect or not, is not answered yet. Neither is the question whether we can find an impact of PCK on students’ achievement gains in other content domains within elementary science education. Further research in different science domains and studies over a longer period of time are needed to answer these questions. If these future research attempts confirmed our findings, one could tentatively conclude that it might be possible to improve students’ learning gains in science by improving teachers PCK. One of the next challenges for teacher research would then be to determine how pre-service and in-service teachers can best be supported in acquiring this knowledge.

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# **SCHOOL CHANGE, TEACHER EDUCATION AND THE ROLE OF MENTORING**

## **- A GERMAN APPROACH IN THE EUROPEAN PROJECT GIMMS –**

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*Abstract:* Schools are experiencing a rapid change of educational practice with an increased demand of professionalism of teachers and teacher educators. Collaborative reflection and discourse in mentoring for teacher education are a basis on which change can occur. In the European GIMMS project (Gender, Innovation and Mentoring in Mathematics and Science) collaborative models of mentoring in science teacher education were studied. The German case study was used as an example of reform in teacher education allowing professional autonomy and critical feedback of teachers in a collaborative model. Beginning teachers accepted the partnership model of mentoring but only within limits concerning cooperation beyond the beginning teacher-mentor relationship. As a reason regularly changing partnerships were noted with unclear requirements of mentors and teacher educators. The many contacts of the beginning teachers do not in advance challenge an innovative mode of reflective teacher education. However mentors seem to operate predominantly with a reflexive mentoring model.

*Keywords:* mentoring, innovation, collaboration, teacher education, science.

### **SCIENCE EDUCATION IN TRANSITION**

Schools not only in Germany but all over Europe are experiencing a rapid change of educational practice in accordance with reform requirements and demands. In order to guide these innovative processes modern solutions in teacher education need to be traced. In educational reform increased professionalism of teachers and teacher educators is of high importance: "What teachers know and can do is crucial to what students learn" (Darling-Hammond, 2000). Programs for professional development, teaching standards or advisory systems in teacher education comprise approaches to change in schools. But what kind of skills and knowledge base are needed for the teaching profession and what kind of support in the process of change?

In science education we see an emphasis on formal reasoning: systematic and disciplined approaches to the teaching of higher order thinking skills (Olson, 2002). Attempts to integrate ideas from outside the sciences or a discourse across or beyond boundaries of science subjects tend to be resisted in traditional practice. But it is not only subject matter knowledge or academic training that account for good teaching. Collaboration among stakeholders and its transformative power of curriculum change is seen as an important element of innovation. This requires professional autonomy and support for discourse between equals of different professional knowledge in school practice. Collaborative reflection and discourse in a network of practitioners and stakeholders is the basis on which change can occur.

A discourse across subjects, in which the value of practice is discussed, not only entails thinking about reorganising subject matter, but finding ways to justify those values for the socialization of learners as citizens and the perpetuation of a society's cultural norms and values. How to achieve this kind of discourse in school systems?

Mentoring in teacher education is seen as chance to generate reflective collaboration leading to innovative processes. Cochran-Smith and Paris (1995) argue that alternative visions of mentoring beyond traditional transmission models are needed to support teachers in collaborative mentoring and reflective practice. There are different perspectives of mentoring represented in models such as described by Maynard & Furlong (1995). They distinguish the apprenticeship, the competency and the reflective model. In our case the *reflective model* is of special interest for innovation in educational. It reflects a partnership based collaboration of initial and in-career teachers and mentors within a community of learners at school, exploring practical experiences in class in a flat hierarchy. However, this process of teacher engagement is not easily achieved. Usually the system of teacher supervision does not allow professional autonomy and collaboration of teachers. The function of teacher supervision is part of a system assessing success in system-wide achievement standards. Such management of teachers does not foster constructive engagement in change. But how can teachers become actors in curriculum reform?

## **INNOVATION AND COLLABORATIVE MENTORING IN THE GIMMS PROJECT**

The European project GIMMS (Gender, Innovation and Mentoring in Mathematics and Science, Mooney & Lang, in preparation) was undertaken against the backdrop of PISA 2003 to 2009 (Klieme et al., 2010) and the teacher policy study "Teachers Matter" (OECD, 2005).

Trends in PISA for each country over the years indicate changes in time possibly due to changes in the educational systems. The OECD (Klieme et al., 2010) interprets this finding that PISA results over a period of years show whether school systems are becoming successful or not in helping students attain an understanding of life in modern society. Concerning gender results, in mathematics boys outperform girls and in science boys and girls perform about the same. The reasons due for these results are manifold. PISA analyzed some of them such as changes in resources, opportunities to learn, standards, achievement assessment or social climate. The quality of teaching was not controlled but seen as a central challenge of the school systems: "There is a lot of evidence, that the professional development of teachers is an outstanding resource for the quality development of the educational system". (Klieme et al, 2010, p. 296; translated from German). These PISA comparative achievement scores and the insight about the importance of teacher professional development were a starting point for curriculum innovation and inclusion work of the GIMMS project.

In the GIMMS project, coordinated by the University of Limerick, collaborative models of mentoring were used to introduce and study innovation in science teacher education. Seven case studies from Ireland, Spain, Germany, Czech Republic, Denmark and Austria demonstrate a big diversity of presuppositions in educational systems and project assumptions and expectations about innovation and teacher education.

Collaboration in the project was mostly realized in small scale mentor-mentee dyads, but also in occasional collaborative groupings of mentors, experienced teachers, teacher educators and groups of mentees. This will be a challenge for schools to support a regular setting for collaborative exchange.

The theoretical framework of this study is curriculum as political text with deliberative discourse for innovation (Aronowitz and Giroux 1991) inside a web of democratic mentoring relationships of learning with colleagues and teacher educators. This implies border crossing of diverse cultures that in a curriculum process of innovation and change. This argument positioned the work of curriculum innovation in each national system or part of it as a cultural field of discourse with diverse voices (Giroux & McLaren 1986). Voice develops through a physical and intellectual journey beyond boundaries of classroom, of disciples, of culture, of home and school learning. This means that curriculum innovation is justified by shared meaning making with a diversity of voices or stakeholders from a variety of communities in open 'public spaces' and not by top down decisions such as national curricula, prescribed standards or unreflected expert statements.

### **Elaborating research questions about innovation and mentoring**

The GIMMS project has one of its focuses on differences and similarities of mentoring in the participating European countries and will use these insights to develop and pilot mentoring relationships between initial and in-career teachers in physics, chemistry, biology, and mathematics. Hence one of the key research questions to drive the project was: How can we develop better partnerships between initial and in-career teachers for continuing professional development and innovation?

### **Structure and methods of the GIMMS case study**

In the GIMMS project national coordinators delivered national and progress reports during a period of three years and participated in interviews. In a final interview they were asked core questions about their national policy with regard to science and mathematics education and innovation, pedagogical practices and changes and models of mentoring. Some of these questions may get us closer to a better understanding of innovative processes and the role of teachers. Outcomes from this will not be offered here in detail but be used as a basis for further analysis of the national case study in Germany as an example.

In all the national cases innovation was judged to be central and during the three years' time of the project realized successfully. Interactions established a stable structure for exchange, generation of new ideas and innovation. The cooperation with teachers triggered discussions about different ways of teaching and mentoring as innovation within different curricular frameworks. This would not have happened in isolated school or university cultures.

## **INNOVATION AND MENTORING: THE GERMAN CASE STUDY AS AN EXAMPLE**

In spite of all the national differences in background and dynamic of innovation in teaching and teacher education there is one consistent driving factor in every of the cases: the interaction of engaged teachers with a university or research and development institution. This answers the question, how teachers become actors in curriculum reform: As actors they need collaborative partnerships to cross boundaries of narrowed school practice.

In the *German* case study student teachers agreed that the intended reform in teacher education allowed professional autonomy and critical feedback of teachers with regularly changing partnerships but this produces some confusion by forcing them to obey different

masters in school and state institutes. Teacher trainers from the state institute IQSH (institute for quality development) and researchers from the national institute for science education (IPN) worked with beginning teachers in the second phase and mentors at a school of these teachers. The idea of the Schleswig-Holstein model was to get away from the old model of study seminar, where only one expert teacher was the main contact person for the beginning teachers moving away from an apprenticeship model toward a more reflective model. The new approach used training modules offered by different persons of the IQSH. Beginning teachers have to learn about these modules and get support from the persons responsible for the module in the IQSH during school visits and mentors at school. The new idea of the work in Schleswig-Holstein with modules and mentors is to be more reflective in teacher education. Questions arise, how this model supports reflective mentoring, how mentors are qualified to participate in reflective practice and what kind of background beginning teachers were bringing to the school as reflective partners.

### Method of tracing innovative aspects of mentoring and gender differences

Six beginning teachers and one mentor of a secondary school in Schleswig-Holstein were asked to participate in the study during the time period of August 2008 and November 2009.

At first a mentor was asked in an interview about the newly introduced official teacher education concept and its adaptation at school, the main tasks of the mentor and the coordinator at the school, the training and certification of mentors. In addition the mentor assembled documents about state requirements for the certification of teachers, the school concept about teacher education and guidelines from the coordinator.

In 2009 a second point of data collection followed with a questionnaire and semi structured interview for beginning teachers. Questions were raised about topics in teacher education, support of beginning teachers' work, collaboration, autonomy and workload in daily practice, gender specific differences and factors for success or failure of beginning teachers. In addition the beginning teachers were interviewed about their experience with the teacher education system and the mentoring process.

In order to trace these questions the model in figure 1 with reflective elements of collaboration was developed:

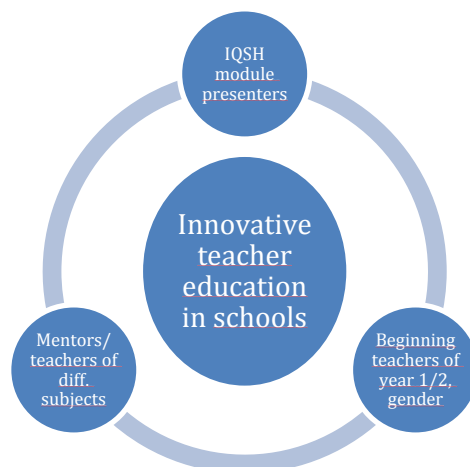


Figure 1: collaborative model about innovative teacher education in schools

In this model the complete system of reflections between mentors/teachers, beginning teachers and module offers of the IQSH teacher training institute for innovative teacher education is outlined. Each outer circle represents a community of educational actors that can interact through boundary crossing with a neighboring community. Within each circle further subsystems can be identified: teachers with or without a mentor status, teachers with different subjects, beginning teachers of consecutive years of training and different gender. It helps to interpret the kind of interactions in statements from questionnaires and interviews done.

## RESULTS

Beginning teachers can choose modules in different subjects and educational topics. Persons from the IQSH present these modules in courses during a full work day in different places. Different modules can be offered by different presenters having different ideas about teaching principles and these teaching principles can be favoured differently by different mentors. Mentors are not always acquainted with the new modules in advance, but they are cooperating with the beginning teachers for preparation of lessons, more often on different levels such as offering practical advice and teaching outlines or discussing typical beginners' mistakes.

A problem with this system of modules is seen in the change of presenters and examiners. Beginning teachers do not have only one person for reference with publicly accountable expectations for their trial lessons and final examinations. This was judged to be more favorable in the old system where there were study guides in fixed groupings. In addition presenters of modules at the education institution and mentor teachers at the school do not have the same background and competencies. Mentors only have a general preparatory introduction into their tasks. These tasks are not related to specific goals for preparation of beginning teachers. A more specific training for mentors is judged to be more favorable.

*Beginning teachers'* answers in questionnaires and interviews partially reflected these critical points of missing coherence between theory in modules and school practice and contradictory demands for examinations. In the questionnaire they agreed that the modules for their subjects were helpful and that they got sufficient support and time for lesson preparation from the school. But they did not find some help in the modules about pedagogy and did not have enough time to cooperate sufficiently with the mentor teacher at the school or to discuss their work or experiences sufficiently with other beginning teachers.

Collaboration was not complete concerning the elements of the above model in figure 1 about innovative teacher education. Collaboration, reflection and exchange, in the larger more extended professional network, between the module presenter, beginning teacher and mentor teacher gives a chance of specific learning for all while linking theory of modules with the practical situation in the classroom. In an interview a beginning teacher is complaining about a lack of specific preparation of mentors for this networking:

*"In general mentors are not well trained. This is obvious ... we as beginning teachers experience, that we are trained very well for the module and then we give our knowledge to the mentors ... They don't know much and in our meetings for consultation the mentors are those, who can say the least about the given lesson. There should be done more so that trainers become trainers, which are now simple teachers who guide us – nothing more."*

To a certain extent a culture of cooperation and autonomy seems to be fostered through partnership based mentoring. Especially beginning teachers from Schleswig-Holstein report a relatively high degree of autonomy and satisfaction about cooperation with colleagues. But



the opportunities for beginning teachers to discuss their work with mentor teachers were estimated to be low. Nonetheless it was lower-order co-operation on the practical and technical aspects of professional work that seemed to dominate the mentoring process.

Content of subjects and its theory in modules seem to be separated from school practice. It clearly needs to be elaborated in congruence with mentor teachers. This point is explicitly made in the following statement:

*“This is absolutely separate. There is something demanded from us by the IQSH [State Institute for Quality Insurance in Schleswig-Holstein] and what we are discussing there with other beginning teachers. And then there is the school, what happens there. And this is completely separated, which is a problem. On the one side we have to do what the module presenter is demanding from us, starting from educational standards, competencies and goals and on the other side in the school they say – pfff – curriculum, educational standards. This is mostly of no interest; they do not know what a curriculum is.”*

Beginning teachers marked in the questionnaire that they missed to a high extent that the module presenters and others as examiners explained the criteria for the examination and that they did not get sufficient help for the examination paper at home. Concerning the demands from module presenters, mentors and the headmaster they feel that they have had to serve different masters with many opposite requirements.

As already mentioned the standards based modules are usually not well known by mentor teachers or principals at the school. This became a problem of agreement between this group of people responsible for the preparation and certification of examinations. In addition different modules may be offered by different presenters having different ideas and ideologies about teaching principles. These teaching principles might then be favored differently by different mentors as reported:

*“The module presenters are not in agreement with their requirements at the end, although there are standards for that and information for preparation defining the criteria for correcting our exam home work ....One time it was required that I show my professional development as a teacher, what I have learnt, how did I manage the lesson and how I profited from that personally. In the other homework I had to show how I supported the pupils, how did I use different criteria for the development of pupils? These are completely different tasks.... This is the point with the mentor that we shall do what we are required but he is not interested in educational standards or methods, there is only interest in subject matter, subject matter, subject matter. ”*

A possible solution to bring greater levels of coherence to these divergent views might be to have a better collaboration between the various actors as suggested in the interview:

*“I have experience about better exchange, defining the other mentor type. I always found out that mentors liked to get material we brought from the modules.... And I believe that it is meaningful that mentors and beginning teachers go together to module meetings. This I have done once with a Math mentor. This is something different, if you meet and can talk together about it.”*

Beginning teachers personally experienced gender differences during their social interactions with the range of actors in their teacher education. They were asked a key question in this regard: How are male and female beginning teachers treated differently? The beginning teachers, especially the female beginning teachers, experienced a difference. They were complaining that their gender made a difference in discussions as pointed out:

*"I experience a higher richness, when men are sitting with us in module sessions. This brings more objectivity in or another point of view, which is not too female."*

Female beginning teachers said that they were treated differently in some ways. When there were only female beginning teachers together, discussions were completely different in the sense that there was no rigorous and a less aggressive demand.

In summary beginning teachers in Schleswig-Holstein seem to experience a high degree of support in their school. Nonetheless there is very little cooperation between initial teachers, beginning teachers and experienced teachers, other than with their specifically nominated mentor teacher. The partnership model of mentoring favored in Schleswig-Holstein does not seem to influence or even foster a culture of cooperation beyond the beginning teacher-mentor teacher relationship. The beginning teachers report very little collaboration within the full community of teachers at the school. There were few reported examples of higher order co-operation. Discussions on teaching experiences and lesson plans were scarce. Cooperative lesson planning rarely ever happens.

The many contacts of the beginning teachers do not in advance challenge an innovative mode of reflective teacher education. However many of the beginning teachers express themselves in the interviews in such a way that the mentors operate predominantly with a reflexive mentoring model.

A possible solution of these divergent views might be a better collaboration as suggested by one teacher. In this case collaboration and exchange between module presenter, beginning teacher and mentor is seen as a chance of specific learning for all, linking theory of modules with the practical situation in the classroom.

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# PERCEIVED PROFESSIONAL DEVELOPMENT NEEDS FOR SAUDI ARABIAN SCIENCE TEACHERS

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*Abstract:* This research looks specifically at the perceived professional development needs for science teachers, so that continuing professional development (CPD) can be planned and implemented. The prime aim of this study was to ascertain the perceived needs of Saudi Arabian science teachers and science supervisors practicing in elementary, middle, and secondary schools. Science teachers were characterized by gender, school location, and area of specialization. The main instrument used was a questionnaire. The validity and reliability of the instrument were systematically established through relevant test procedures. The questionnaire seeks feedback on the main aspects of science teachers' needs, including generic pedagogical knowledge and skills, knowledge and skills in science subjects, managing and delivering science instruction, diagnosing and evaluating students, planning science instruction, administering science instructional facilities and equipment, integration of multimedia technology, and informal science learning. Additionally, the questionnaire covered the key science subject domains in which science teachers might need professional development. This study argues that science teachers' voices concerning their professional development needs are the key guide for their CPD.

*Keywords:* Teachers' professional development needs- Continuing Professional Development- Teacher Education

## INTRODUCTION

Teacher professional development is a prominent feature on the educational landscapes of developed and developing countries equally. Experience around the world in developing, industrialized, and information-based countries has shown that professional development is the key determining factor for improved student performance. Effective professional development experiences are designed to help teachers build a new understanding of teaching and learning (Lee, 2001). Teacher development can be conceptualised as a mechanism for driving change in educational systems and/or as a strategy for empowering individuals and teams to improve their professional knowledge and pedagogy (Day & Sachs, 2004). Dillon (2010) argues that teacher development can either play a critical role in meeting teachers' needs and wants, or it can frustrate teachers and keep them from reaching their full potential. He also argues that teachers might both want and need professional development. In contrast, someone in a different profession, such as an inspector or a line manager, might identify that an employee has a need that they themselves are unaware of, such as a need for training in different questioning techniques. Nevertheless, for the purposes of this paper, we will explore the difference between the needs required for teaching science effectively represented by the inspectors' opinion, and the needs of teachers.

The continual deepening of knowledge and skills is an integral part of the development of any professional working in any profession. One important means of achieving competitive advantage is the creation of conditions for the rapid acquisition of new knowledge and skills. Teaching takes place in a world dominated by change, uncertainty and increasing complexity. Government publications all over the world, in Europe, North America and the Antipodes stress the technological, economic and social challenges which schools, and therefore teachers, face (Day, 1999). From the professional development view, Borko and Putnam (1995) argue that current educational reform recommends a shift toward a student-centred paradigm. This entails a substantial departure in teachers' approaches, from a traditional transmission of knowledge to a cognitive and social construction of knowledge. The tradition of 'in-service days' as the norm in professional development has been criticized as inadequate and inappropriate in the context of current educational reform efforts, and as being out of step with current research about teacher learning (Darling-Hammond & McLaughlin, 1995). One possible reason for the unsatisfactory results of in-service teacher training might be that the objectives of programmes were not congruent with teachers' personal and classroom needs (Baird et al., 1993). It might be reasonable to better understand the target audience before prescribing any intervention. Thus, to simply impose a training programme on teachers without considering their needs makes little sense (Noh, Cha, Kang, & Scharmann, 2004). Baird and Rowsey (1989) also highlight teachers' complaints that much time spent during in-service programmes and activities was wasted when such programmes did not meet their respective classroom needs. Loughran and Invarson (1993) argue that it is important that as a profession we are able to articulate what science teachers need to know and are able to do.

The concept of need has diverse interpretations. In the literature 'need' is used variously to mean a discrepancy, a recognized problem, the requirement for more services, and the wants of people (Stufflebeam, Mc Cormick, Bronkerhoff, & Nelson, 1985; Packwood & Whitaker, 1988). For this study, need is defined as the wants or preferences of an individual or a group of people. Need in this context is seen as a want (which implies interest or motivation) felt by an individual or group to eliminate a lack (Queeney, 1995). Without identification of teacher needs, poorly directed and inadequately focused interventions may emerge (Rhodes & Beneicke, 2003).

Educators acknowledge that the quality of science instruction is the main factor in developing meaningful understanding of science. Furthermore, the quality of science instruction cannot be achieved without qualified science teachers (Carey, 2004). Therefore, any mature reform of science education should emphasise science teacher professional development programs. These programs should help teachers develop in-depth knowledge of their disciplines as well as pedagogical content knowledge and skills (Mansour, 2010b). Consequently, the professional development of science teachers is widely recognised as a national priority (Obikan for Research and Development, 2010). The Excellence Center of Science and Mathematics Education ECSME at King Saud University in Saudi Arabia considers research in the professional development of science teachers as a key element in the reforming process of science education in Saudi Arabia. Therefore, ECSME launched a group to conduct a series of researches with science teachers and science teacher supervisors to develop a continuing professional development (CPD) program. The purpose of the program would be to support science teachers to take an active role in science education reform in Saudi Arabia. Accordingly, in the current study the research group aimed to identify and explore science teachers' needs in both content and pedagogical knowledge and skills as a first step toward

making decisions and recommendations about the elements of CPD program(s) required for science teachers. The following two research questions were used:

1. What professional development needs in science content knowledge are identified by science teachers and their supervisors in Saudi Arabia?
2. What professional development needs in pedagogical knowledge and skills are identified by science teachers and their supervisors in Saudi Arabia?

## METHODOLOGY

### Instrumentation

To collect the data, the researchers developed a questionnaire based both on their experiences and on a review of a related study. The questionnaire includes 40 items (21 items for the science content knowledge domain and 19 items for the pedagogical knowledge and skills domain). Cronbach's coefficient alpha was used to calculate the internal consistency coefficients of the questionnaire. Results of the reliability analysis showed that the items in the instrument had a satisfactory discriminating power. Reliability coefficient alpha obtained for the whole instrument was 0.973; however, the coefficient alpha for the two scales were 0.978 and 0.973 respectively for the science content knowledge domain and the pedagogical knowledge and skill domain.

### Collection of Data and Sampling

The population of this study included 2701 Saudi science teachers and 66 science teacher supervisors in four educational districts in different parts of Saudi Arabia (Jeddah, Alkarj, Alzulfi, and Almeqwah districts). These districts were chosen because they were parts of the partnership program with the Centre of Science and Mathematics Education which is the sponsor for this study. All science teachers in these districts were considered as the population and the sample of this study; a representative was hired in each educational district to distribute the questionnaire to all science teachers and supervisors in each educational district. A total of 499 Saudi science teachers and 61 science teacher supervisors responded to the questionnaire. For science teachers, the respondents included both sexes: 209 (42%) were female and 290 (58%) were male. Concerning subject specialism, it was found that the respondents were drawn from the following disciplines: biology 33.3%, physics 16.6%, chemistry 16.4%, earth sciences 2.0, other subjects (those who teach since for elementary students, but are not specialized in science) 27.1%. The 61 science teacher supervisors included both genders: 48 (78.7%) were female and 13 (21.3%) were male.

## FINDINGS

### The needs in science domains perceived by teachers and supervisors.

Table 1 summarizes the perceived needs of science teachers and their supervisors for professional development in various science subjects. As shown in Table 1, the 10 top needs perceived by teachers were the following: 1. nature of science and scientific inquiry, 2. modern physics, 3. structure and function of human systems, 4. genetics and evolution, 5. Electricity and magnetism, 6. earth properties and physical processes, 7. chemical reactions, 8. Forces and motion, 9. energy and 10. energy and chemical changes. These needs had a sequential priority mean of 3.53, 3.47, 3.46, 3.45, 3.43, 3.42, 3.41, 3.41, 3.40, and 3.39, respectively. In contrast, the 10 top needs perceived by science supervisors were the following: 1. the solar system and the universe, 2. Nature of science and scientific inquiry, 3.

Forces and motion, 4. plants, 5. climate and weather, 6. Structure and properties of matter, 7. Genetics and evolution, 8. Chemical reactions, 9. Earth properties and physical processes modern physics and 10. Energy and chemical changes.

These needs had a sequential priority mean of 4.51, 4.41, 4.25, 4.15, 4.02, 3.98, 3.94, 3.89, 3.80, and 3.78, respectively. Six out of the top 10 perceived needs were the same for both science teachers and their supervisors. These six needs are Genetics and evolution, energy, forces and motion, energy and chemical changes, chemical reactions, Earth properties and physical processes, and the nature of science and scientific inquiry. However, as shown in Table 1 the priority among these six perceived needs was different for science teachers and science supervisors, except for energy and chemical changes, which was ranked 10 by both science teachers and science supervisors. These findings might raise important questions about the validity of the science supervisors' voice regarding the CPD required for teachers. They also raise a question about the science supervisors' awareness of the science teachers' needs.

Table1

Science subject knowledge perceived by science teachers and by supervisors

No	Items	Science teachers		Science supervisors		t	df	Sig. (2-tailed)
		M	SD	M	SD			
1	Structure and function of human systems (biology)	3.46 (3)	1.088	3.75	1.004	1.673	546	.095
2	Epidemics: Causes and ways of prevention(biology)	3.38	1.115	3.48	1.047	.476	548	.634
3	Living things (biology)	3.33	1.103	3.49	.984	.772	545	.440
4	Plants (biology)	3.32	1.145	4.15 (4)	.951	4.954	541	.000
5	Genetics and evolution (biology)	3.45 (4)	1.159	3.94 (7)	.826	3.188	551	.002
6	Electricity and magnetism (physics)	3.44 (5)	1.102	3.73	1.056	1.910	545	.057
7	Energy (physics)	3.40 (9)	1.088	3.47	1.112	1.081	549	.280
8	Structure and properties of matter (chemistry)	3.32	1.101	3.98 (6)	.975	4.130	549	.000
9	Forces and motion (physics)	3.41 (8)	1.098	4.25(3)	.888	5.571	549	.000
10	Modern physics (physics)	3.47 (2)	1.149	3.77	.890	1.945	547	.052
11	Light and sound (physics)	3.40	1.137	3.72	.951	2.043	549	.042
12	Energy and chemical changes (chemistry)	3.39 (10)	1.120	3.78(10)	.937	2.359	550	.019
13	Chemical reactions (chemistry)	3.41 (7)	1.165	3.89 (8)	.958	-2.959	551	.003
14	Structure of matter and chemical bonding (chemistry)	3.36	1.125	3.46	1.104	.562	545	.574
15	Environment and the effect of environmental pollution (biology)	3.36	1.127	3.75	.943	2.483	548	.013
16	Climate and weather (Earth science)	3.30	1.132	4.02 (5)	.956	4.514	541	.000
17	Earth properties and physical processes (Earth science)	3.42 (6)	1.115	3.80 (9)	.953	2.423	544	.016
18	The solar system and the universe (Earth science)	3.37	1.141	4.51 (1)	.698	7.468	547	.000
19	Nature of science and scientific inquiry	3.53 (1)	1.138	4.41 (2)	.761	5.732	550	.000

The number in parentheses represents the priority of the perceived need

An independent sample t-test was conducted to see whether there was a difference between teachers and supervisors in their perceptions of teachers' CPD needs in science domains. As shown in Table 1 there was not a statistically significant difference, except on three subject knowledge questions: living things, energy and structure of matter, and chemical bonding. The means of supervisors' responses of these three domains (3.33, 3.47, and 3.46, respectively) were higher than those of teachers' perceived needs to the same topics (3.33, 3.40, and 3.36, respectively). This can be explained by the fact that the supervisors do not hold sufficient knowledge about teachers' needs concerning the science domains.

## The needs in pedagogical knowledge and skills perceived by teachers and supervisors.

Table 1 summarizes the perceived needs of science teachers and science supervisors for professional development on pedagogical knowledge and skills. As shown in Table 2, the 10 top needs perceived by teachers were the following: 1. teaching science through field trips and scientific visits, 2. developing creative thinking among students, 3. teaching science for gifted students, 4. developing Science concept among students, 5. associating technology with teaching, 6. planning for teaching, 7. scientific inquiry instruction based in science, 8. Teaching science for special need students, 9. instruction based problem solving in science and 10. using concept mapping. These needs had a sequential priority mean of 3.68, 3.66, 3.64, 3.60, 3.57, 3.55, 3.54, 3.52, 3.51, and 3.50, respectively.

Table 2

Need of Pedagogical knowledge and skills as perceived by in-service science teachers and supervisors

No	Items	Science teachers		Science supervisors		t	df	Sig. (2-tailed)
		M	SD	M	SD			
1	Teaching theory, such as constructivism, behaviourism	3.50 (10)	1.038	4.28	.878	5.756	549	.000
2	Classroom management skills	3.28	1.155	4.38 (10)	.840	7.271	554	.000
3	Associating technology with teaching	3.57 (5)	1.122	4.36	.817	5.497	547	.000
4	Using labs in teaching science	3.55 (6)	1.189	4.46 (8)	.773	5.823	549	.000
5	Assessing students' learning	3.33	1.127	4.16	.970	5.520	548	.000
6	Planning for teaching	3.28	1.148	4.13	.903	5.748	551	.000
7	Connecting science to students' real lives	3.32	1.207	4.70 (2)	.691	8.688	550	.000
8	Scientific inquiry instruction based in science	3.54 (7)	1.113	4.69 (3)	.564	7.794	547	.000
9	Instruction based on problem solving in science	3.51 (9)	1.091	4.05	.884	3.894	549	.000
10	Using concept mapping	3.45	1.102	4.16	.840	5.072	544	.000
11	How to teach specific science topics, such as magnetism or writing chemistry equations	3.38	1.099	4.30	.955	6.138	554	.000
12	Questioning and classroom discussion techniques	3.32	1.176	4.42 (9)	.747	6.968	553	.000
13	Teaching science through field trips and scientific visits	3.68 (1)	1.111	4.74 (1)	.480	7.230	547	.000
14	Developing creative thinking among students	3.66 (2)	1.041	4.52 (7)	.748	6.066	546	.000
15	Developing science concepts among students	3.60 (4)	1.018	4.68 (4)	.596	7.873	541	.000
16	Teaching science for gifted students	3.64 (3)	1.074	4.56(6)	.643	6.771	540	.000
17	Teaching science for special needs students	3.52 (8)	1.183	3.98	.904	2.904	545	.004
18	Content analysis	3.42	1.040	4.60 (5)	.588	8.634	544	.000
19	Teaching science using learning cycle	3.49	1.052	3.95	.825	3.256	542	.001
20	Connecting science to other courses	3.41	1.093	4.00	.876	3.968	540	.000
21	Connecting science topics to each other	3.44	1.110	4.28	.878	389	484	.697

The 10 top needs perceived by science supervisors were the following: 1. teaching science through field trips and scientific visits, 2. connecting science to student the real Life, 3. scientific inquiry instruction based in science, 4. developing science concept among students, 5. content analysis, 6. Teaching science for gifted students, 7. developing creative thinking among students, 8. using labs in teaching science, 9. questioning and classroom discussion technique and 10. classroom management skills. These needs had a sequential priority mean of 4.74, 4.70, 4.69, 4.68, 4.60, 4.56, 4.52, 4.46, 4.42, and 4.38, respectively. Six out of the top 10 perceived needs were the same for both science teachers and supervisors. The six needs are these: 1. using labs in teaching science, 2. scientific inquiry instruction based in



science, 3. teaching science through field trips and scientific visits, 4. developing creative thinking among students, 5. developing science concepts among students, and 6. teaching science for gifted students. However, as shown in Table 2 the priority among these six perceived needs by both science teachers and science supervisors was different, except for Teaching science through field trips and scientific visits, which was ranked 1 by both science teachers and science supervisors.

An independent sample t-test was conducted to see whether there was a difference between teachers and the supervisors in terms of teachers' CPD needs for pedagogical knowledge and skills. As shown in Table 2 there was a statistically significant difference between teachers' and supervisors responses, except that there was not a significant difference on one item—Connecting science topics to each other. The means of supervisors' responses on these three domains ( $M = 4.28$ ) were higher than that of teachers' perceived needs for this skill ( $M = 3.44$ ). This can be explained by the fact that the supervisors do not hold sufficient knowledge about teachers' needs concerning the science domains.

## DISCUSSION AND IMPLICATIONS

The majority of the teachers in the current study expressed a great need for academic and pedagogical training. The findings reflected that teachers perceive that they lack basic knowledge (e.g., chemical bonding, structure and properties of matter, forces and motion, and structure and function of human systems) and skills (e.g., planning for teaching, using labs in teaching science, and scientific inquiry instruction in science) to teach science. These findings might be interpreted as meaning that teachers believed their pre-service and in-service education did not help them in teaching science as it should be taught. Therefore, science educators should be aware of science teachers' professional needs in both pre-service and in-service training to use the pedagogies that can promote these 21st century skills e.g. teaching science for creative thinking, teaching science for gifted students, teaching science through field trips and scientific visits, connecting science to students' real lives etc.

The results from this study indicate that there is a mismatch between teachers' perceptions of their CPD needs and their supervisors' perceptions. While teachers are particularly concerned with the quality of science education, other stakeholders, such as science supervisors in this study, may have different priorities. In this sense, the findings of the current study concur with Park Rogers et al. (2006)'s study that the difference in beliefs among the stakeholders of professional development PD that has contributed to the gap between ideal and actual PD practice. Park Rogers et al (2010: 313) argue that "individual orientations to teaching science teachers do exist, can impact science teacher education activities, and can also change". A balance is required that addresses the concerns of everyone involved by reconciling competing interests. In this sense, Clandinin (1992, p.136) argues that teacher education should involve 'highlighting the tensions between personal and institutional narratives' so that reflection can be made to be powerfully relevant through focusing on the contrast between how teachers and institutions see each other and how they see themselves. Additionally, teachers' voices should be heard and taken into account concerning their perceived professional needs and the practical problems they face when implementing any new ideas in the classrooms.

The present study provided an insight for science teacher education. It will be useful for science teacher educators since it aims to meet science teachers' professional needs. According to Mansour (2010b), one reason why previous science education reform efforts have failed is because a consistent and coherent set of purposes, policies, programmes, and

practices do not exist. Setting policies or curriculum frameworks at the state, county or even the school level can influence practice in the classroom, but may not ensure that science teachers will appropriately or consistently translate the policies into practice (Mansour, 2010a). Therefore, science teachers, supervisors, policy makers, and in-service and pre-service programme planners need to work together to consider the recommendations that have been identified in the teachers' professional development research.

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## SCIENCE TEACHERS' PERCEPTIONS ABOUT THE RELATIONSHIP BETWEEN RESEARCH AND PRACTICE

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**Abstract:** This article discusses science teachers' perceptions of their own experiences in research or innovative programs, identifying positive and negative aspects of these experiences. Data was collected from 1290 science teachers within a large-scale questionnaire of TRACES project, developed in collaboration with universities from Argentina, Brazil, Colombia, Israel, Italy and Spain. Results showed around half of the teachers (44.7 %) have participated in some kind of innovative or research experience. These experiences are strongly cultural dependent. The high frequency on innovative programs (36,4%), which are usually proposed by public policies, indicates the teachers conception of innovation as produced externally, as something that is received in the school and reproduced (top-down). Teachers seem to assume a passive role in this process. The positive perceptions of these experiences were organized in the following categories: professional development; increasing in teachers and students autonomy; opportunities to develop peer-to-peer learning and good practices exchange; improvement of teachers' reflexive thinking; fitting the content to the context; development of procedural and attitudinal students learning; development of student's conceptual learning; and opportunities to experience research methodologies. The negative perceptions about teachers' participation in research were: lack of time and material resources; lack of engagement of the school community; lack of continuity and information about research results; lack of training and experience in research; administrative obstacles; and lack of connection between research and school context.

**Keywords:** teachers' perceptions; research experience; innovative experience; science education; TRACES.

### BACKGROUND AND PURPOSE

This article presents partial results produced from the project TRACES - Transformative Research Activities: Cultural Diversities and Education in Science, funded by FP7<sup>1</sup>, developed in collaboration with universities from Argentina, Brazil, Colombia, Israel, Italy and Spain. This project aims to identifying in each country the difficulties to bridge the gap between science education research results and the actual application of these results in teaching practice in schools. Within a transformative perspective, it also aims to involve all the actors (teachers, students, parents, researchers and policy makers) in the development of significant practices; as well as the elaboration of guidelines in order to improve scientific education.

TRACES project was structured in three main stages. During the first stage, in each partner country, consortium members carried out a survey of policies for science education improvement (national plans, projects and experimentations, curriculum reforms, institutional guidelines) implemented at national level during the last years. A parallel survey investigated the perspectives of

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<sup>1</sup> TRACES: Transformative Research Activities, Cultural Diversities and Education in Science. FP7-SCIENCE-IN-SOCIETY-2009-1-244898.

the different actors (policy makers, teachers, researchers) involved in this process about the impact of those initiatives and of science education research, the possible barriers on the path towards their translation in actual teaching and learning practices at school. In the second stage, the consortium planned field actions in each partner country, inspired by the rationale shared in the first stage of the project and by research findings. The actions were designed and carried out by local project groups, involving the actors in an action-research process. In the third stage, lessons learned from the two previous phases will be put together and brought to a common ground at the consortium level, in order to compare results and come to a common reflection.

This article presents a development of the first stage of TRACES project, in which the science teachers' perceptions about their own experiences in research or innovative programs, as well as the positive and negative aspects of these experiences are investigated.

The research questions that guided this study were: (1) What are the science teachers' experiences in research or innovative programs? (2) What positive aspects are identified by the science teachers in their experiences in research or innovative programs? (3) What negative aspects are identified by the science teachers in their experiences in research or innovative programs?

## **RATIONALE**

Different hypotheses have been investigated to account for a perceived lack of connection between research and practice. Hargreaves (1996, cited by McIntyre, 2005) complained that researchers often determine the agenda for educational research, and teachers are not even seeing the lack of evidence-based research as a problem in urgent need of remedy. For McIntyre (2005), the knowledge needed by classroom teachers in their everyday work and the knowledge that educational research is well equipped to provide are of two different kinds. Research-based knowledge may be used as a contributing element to pedagogical knowledge, but it cannot be simply translated into pedagogical knowledge. Teachers use to give priority to practicality, while researchers are obliged to prioritize values relating to the clarity and coherence of arguments and to the truth of their conclusions. The nature of research-based knowledge is impersonal and the nature of teaching is highly personal.

There is a myth suggesting that science teachers in the primary and secondary schools do not want to hear about educational research related to their field. Luft (2010) states that teachers are interested in talking to colleagues about emerging issues in science education, and to participate in science education research. While there are science education researchers and teachers who bridge the gap research-practice, few projects have significant collaboration in order to produce a shared product.

As pointed by McLaughlin and Black-Hawkins (2004), teachers use to see the conducting of research as an add-on activity, while colleagues from university consider schools as simple sites for their research. However, the authors present several patterns or models of school-university research partnership, from research conducted by individual teachers and their students to research conducted by teachers and academics for the wider audience of educational community.

The distinctions between schools and universities do not necessarily cause conflict, nor do they necessarily act as barriers to different forms of knowledge generation. However these partnerships are most successful where there is a shared understanding of these differences, as well as an acceptance of the appropriateness of one another's concerns, a readiness to be helpful wherever possible, and a recognition that each could learn much from the other (McLaughlin & Black-Hawkins, 2007).

The main challenges and dilemmas for all those engaged in collaborative school-university research are mainly the conditions to support the research activities, the roles of teachers and academics, and the nature of knowledge created. This article enquires the nature of these challenges from the teachers' perceptions with respect to their own views and experiences in research and innovative programs.

## METHODOLOGY

This paper presents a qualitative research (Lüdke & André, 1986; Bogdan & Biklen, 1994; Flick, 2009) and it was based on science teachers answers for one question posed in the TRACES large-scale questionnaire, containing 36 questions, including opened and closed questions, applied to the six countries of the consortium: *Have you already participated of some innovative program or research inside or outside the university? (Yes, No) Describe the positive or negative aspects of this experience.*

The sample consisted of 1290 science teachers from all six countries. Of these participants, 577 teachers (45%) answered YES, informing that they have participated in some research or innovative program. For this study we analyzed the description of these experiences and the positive and negative aspects of these experiences, only those who claimed to have participated. The data analysis was restricted to teachers who are working with science subjects at primary and/or secondary schools.

To analyze the data we have associated quantitative and qualitative approaches, to obtain results with global and particular evidences about the science teachers' perceptions of their experiences in research or innovation. Regarding the qualitative data analysis, Alves-Mazzotti and Gewandsznajder (1998, p. 170) point out that "[...] this is a complex, nonlinear process, which implies in a work of reduction, organization and interpretation of data which accompanies the entire investigation". In the present study, we used the Discursive Textual Analysis (DTA) (Moraes & Galliazzi, 2007). The DTA method of analysis is organized around four main stages: (1) 'Unitarization', characterized by the deconstruction of texts to identify and isolate ideas. This disassembly process results in 'units of analysis', which represent "elements relating to the phenomenon which is being investigated" (Moraes, 2003, p.195). (2) Categorization, in which the units of analysis are grouped into initial categories. In the subsequent step, the initial categories are grouped in a lower number and more comprehensive categories, called intermediate categories. Finally the intermediate categories are organized in a lower number of categories. The criterion used for the categories construction is the linkage with the ideas initially fragmented. (3) 'Meta-text', in which a rigorous analysis of the categories formed gives rise to the production of different text types, called 'meta-texts', which are continuously improved resulting in the construction of the final text, and comprises the description and interpretation. (4) Communication, the last stage of DTA, in which the constructed arguments are disseminated.

Therefore, DTA is an open methodology, a process of self-organization, consisting of construction, deconstruction, rigorous analysis and data validation. The validity and reliability of the results are guaranteed by the strictness with which each analysis step of the methodology is conducted (Moraes & Galiuzzi, 2007).

## RESULTS

The results showed that half of the science teachers (45 %) in our sample have participated in some kind of research or innovative experience. Among those who responded affirmatively, 59% described their experiences. Table 1 shows the frequency of teachers' participations in research or innovative programs for each country of the consortium, and the number of experiences described.

**Table 1 – Teachers' participation in research or innovative programs for each country.**

Countries	Total sample	Participation in Research/Innovative Programs (YES)	Experiences described
Argentina	436	134 (31%)	99 (74%)
Brazil	136	66 (49%)	20 (30%)

Colombia	170	136 (80%)	108 (79%)
Israel	64	36 (56%)	15 (42%)
Italy	279	94 (34%)	14 (15%)
Spain	205	111 (54%)	82 (74%)
<b>TOTAL</b>	<b>1290</b>	<b>577 (45%)</b>	<b>338 (59%)</b>

Among teachers who pointed their participation in research or innovative programs, it was possible to identify different types of experiences, highly dependent on the cultural background in each country (Table 2).

**Table 2 – Type of teachers’ experiences in research or innovative programs.**

Type of Experiences	Frequency	Percentual
Innovation programs (regional/national/public policies)	123	36.4%
Research Projects (school-university)	73	21.6%
Short-term Training Courses	39	11.5%
Long-term Training Courses	35	10.4%
Other innovative programs (interdisciplinary X disciplinary)	33	9.7%
Others (developing teaching materials, using informal environments and training offered)	35	10.4%
<b>Total</b>	<b>338</b>	<b>100.0%</b>

The higher frequency of teachers’ experiences was on innovative programs (36,4%), which were defined in this work as those science programs proposed by public policies. This number indicates that teachers’ conception of innovation are usually identified as something produced externally, and received in the school for reproduction. This top-down innovation approach use to be led by public authorities or an ‘expert bringer’, and teachers seem to assume a passive role in this innovative process. For example, in Argentina, a high incidence of “science fairs” experiences (30%) as a research/innovative experience was identified. Considering that this Argentinean program is part of a national policy, the results increased the first category.

The partnership model with school-university developing a research project involving groups of teachers and/or students was the second most frequent experience. In Colombia, the high score of research experience (47%) seems to indicate a strong partnership school-university or, on the other hand, a non-canonical understanding of “research or innovative programs”.

Teachers also identified their participation in short and long-term teacher training as a research experience, which includes short training courses on the one hand, and master programs in the other. Finally, interdisciplinary projects involving the whole school and the production of new teaching materials were also identified as research/innovative experiences.

The positive aspects highlighted by teachers were grouped in eight categories: improvement of teaching practice (51%); contribution to increasing autonomy of teachers and students (28%); opportunities to develop peer-to-peer learning and good practices exchange (20%); teachers’ reflexive thinking (18%); fitting the content to the context (18%); students’ procedural and atitudinal learning

(17%); students' conceptual learning (12%); and opportunity to experience inquiry-based methodologies (11%).

Chart 1 shows some quotes of positive aspects extracted from teachers' textual answers.

**Chart 1 – Distribution of positive aspects of involvement with research, by category.**  
**Quotations about the participation in innovative programs and research**

Improvement of teaching practice	<p><i>"It is positive for teachers, because they can improve their practice, which reflected positively in students leaning process"</i></p> <p><i>"First, it forces you to think about your daily practice. Secondly you know what is being done on the teaching of your subject. Thirdly you can learn and improve."</i></p>
Contribution to increasing autonomy	<p><i>"The project led me to a conceptual change, my approach to students and teaching has changed significantly. By becoming a facilitator instead of a source of knowledge I learned to believe in students' ability to succeed and achieve better."</i></p> <p><i>"The positive is that encourages both the teacher and students and parents learn investigating."</i></p>
Opportunities to develop peer-to-peer learning and exchange of good practices	<p><i>"I learned from my colleagues and felt the brainstorming advanced me."</i></p> <p><i>"Understanding and exaltation of the need to work on a common science teachers' network."</i></p> <p><i>"We share with our fellows, receive advice from different people which are 'experts'."</i></p>
Improvement of teachers' reflexive thinking	<p><i>"I learned a lot from working with developers. I learned new things about myself which I haven't noticed before, and improved my teaching, as well as learned about this interesting area."</i></p> <p><i>"It is a stop on the inertial operation for rework objectives of our work."</i></p>
Fitting the content to the context	<p><i>"The positive aspect lies in the contributions that can be done not only to scientific knowledge of the country and the world, but also make contributions to the area where you work and have a defined life plan."</i></p> <p><i>"Forces the constant reflection with peers or individually on what we want our students to learn and therefore helps to better relate to them."</i></p>
Contribution to students' procedural and attitudinal learning	<p><i>"The fact of having done research, allows us to better instill our students with the advantages of the scientific method and critical thinking in any situation."</i></p> <p><i>"It created teamwork that favored the group of students, as evidenced the need for teamwork as an important part of the educational activity."</i></p>
Opportunity to experience research methodologies	<p><i>"It is positive to place the child in contact with scientific knowledge, where they can make observations, formulate hypotheses, register and assemble their notes, draw conclusions and transmit it to others."</i></p> <p><i>"The most positive thing was the guidance in the process to raise the research problem."</i></p>

Although these positive aspects, teachers that experienced research/innovative activities complained about: lack of time and material resources (43%); lack of engagement of the school community (27.4%); lack of continuity and information about research findings (21.4%); lack of

teachers training and experience in enquiry (14.2%); administrative obstacles (13.2%); and lack of connection between research and school context (9.6%).

Chart 2 shows the distribution of the negative aspects pointed out, summarized in those six main categories. Moreover, some quotes are presented as examples, extracted from teachers' textual answers, in each category.

**Chart 2 – Distribution of negative aspects of involvement with research, by category.**

Category	Quotations about the participation in innovative programs and research
Lack of time and material resources	<p><i>"I see that there is a lack of incentives for institutional research in the organizations, whether in budget or logistics."</i></p> <p><i>"Not rewarded or recognized school teacher we do extra work to innovate in our classrooms".</i></p>
Lack of engagement of school community	<p><i>"The negative side is the resistance from many older and experienced teachers in accepting new teaching methodologies."</i></p> <p><i>"Often people who want to do different activities or proposals, are few. Sometimes they even are viewed critically by peers. Make innovation is hard work and not always appreciated by the rest of the faculty."</i></p>
Lack of continuity and information about research findings	<p><i>"The group of teachers who are part of innovation and research programs is always the same, hardly increases."</i></p> <p><i>"It was negative due to the lack of funding and the continuity of the research program. Teachers have difficulties to leave the classroom."</i></p>
Lack of teachers training and experience in research	<p><i>"The little ownership of some teachers with the proposed methodology."</i></p> <p><i>"It would be interesting to those who work at the basic level of primary or secondary could also enjoy and have the possibility of a sabbatical year as in the universities to devote to pure research."</i></p>
Administrative obstacles	<p><i>"Requires significant time and dedication has minimal recognition by the administration."</i></p> <p><i>"The feeling that there is a great personal effort, and there is very little recognition and support for continuing by the administration. The changes require the support and the duration is long."</i></p>
Lack of connection between research and school context	<p><i>"Sometimes they are working on issues or topics that are very difficult to implement in daily practice. Also sometimes these programs are not sufficiently disclosed."</i></p> <p><i>"Trainers sometimes do not prepare us for what we found in the classroom. Should be more practical. The paper bears all, but the day to day in the classroom has some problems that are not covered from the theory."</i></p>

In teachers' opinion, the most critical negative aspect of their involvement in research/innovative programs is the lack of time and material resources. They complain about the absence of effective support from faculty and school principals, expressed by their quotations about loneliness and administrative barriers. The lack of ongoing relationship with researchers is quoted by teachers, reinforcing the importance of a stronger, closer and continuous university-school partnership. Despite teachers complain about the lack of information about research findings, they believe the contribution of research findings can transform and modify teaching practice and the positive contribution of inquiry-based approaches is extended to students' learning.



## CONCLUSIONS

The results show that the most common science teachers' experiences in research/innovative programs are those mentored by public authorities/research experts and collaborative research experiences. In both experiences, research activities are predominantly led by teachers, but restricted to classroom experiences with students of each individual teacher. The collaboration between groups of teachers and students, supported by faculty members is also identified in their experiences.

The main contribution of this experience, highlighted by science teachers, is their professional development, showing the importance of introducing inquiry-based activities in pre-service teacher training, which provides a critical opportunity to bridge the gap research-teaching practice.

In the teachers' perception in all six countries, there is a lack of incentive and support for research activities as a pedagogical activity developed in schools. Teachers see the conducting of research activities as an add-on activity. The engagement and commitment of school leaders to keep research activities in their own schools should be particularly valuable to overwhelm these barriers.

There is a coherent relationship between negative and positive aspects in the research experience. They complain about the lack of engagement and support of the school community in research activities, whereas in the other side, they indicate the opportunities to develop peer-to-peer learning and exchange of good practices as positive. As a counterpoint to the lack of teacher training in research, they emphasize this experience to empower teachers in research or inquiry-based methodologies. They complain about the lack of connection between research findings and school curriculum, and from the other side, research is seen as a way to fit the school content to the context of students and/or community.

Concluding, the challenges for bridging the gap between research and practice can be related to two contexts: the school context, which should promote support for teachers engagement in research; and the academic context, which should ensure the establishment of long-term partnerships, bringing academic research close to school context and improving teacher training in research.

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# **PATTERNS IN THE MEANING-MAKING OF SCIENCE TEACHERS INVOLVED IN A TEAM-BASED PD-PROJECT**

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*Abstract:* The perceived outcomes of four science teachers involved in a yearlong school-based professional development (PD) project analyzing artifacts from practice in local science classrooms are examined through repeated interviews and are represented as meaning-making maps for each teacher. The teachers refer to various outcomes from the project and emphasize those parts of the project where they personally feel supported in relation to the current tensions they are experiencing in their professional work. Beside this there are similarities; all teachers refer to experiences from experiments in professional practice, and reflect on and interpret those experiences in relation to student learning. They also seem to grow to acknowledge the value of sharing practice through the facilitated collegial interactions.

*Keywords:* Professional development, meaning-making, in-service, professional learning, artifacts from practice

## **INTRODUCTION**

It is acknowledged internationally that there is a need to improve science teaching, that science teachers are the key to this development and that professional development (PD) activities the teachers are engaged in can play a crucial role (e.g. Feinam-Nemser, 2001). In Denmark a number of science teachers have been educated to diploma level in recent years and act as resource teachers within their schools to support PD. However PD for most science teachers is still short, out-of-school courses detached from practice in spite of a growing consensus on the most beneficial approaches to teachers' PD. It appears that PD gains from being school based, focused on student learning, long term, content focused, and collaborative, and from incorporating inquiries into practice (Roth, 2007; Borko, 2004). The sharing of classroom videos in video clubs has been reported to produce a focus shift towards student learning (Sherin and Han, 2004), and there is a growing acknowledgment of the role played by cooperation among colleagues, teacher learning communities, with respect to an individual teacher's learning (McLaughlin and Talbert, 2006).

Teachers' professional learning can be seen as a change in knowledge and beliefs and/or a change in teaching practice (Bakkenes, Vermunt, and Wubbels, 2010; Borko, 2004). With a socio-cultural perspective acknowledged, and with the knowing and learning of teachers seen as constructed through participation in different aspects of local practice and discourse (Borko, 2004; Edwards 2001) research must seek an understanding of the teachers' experiences, how they make sense. The term meaning-making has been used for two decades in part of the research into students' learning in science classrooms (Abell, 1992; Mortimer and Scott, 2003). Meaning-making can when discussing (science) teachers' professional learning be conceptualized as a fine-grained perspective on their on-going construction of understanding and interpretation of experience in a particular setting or context.

The interconnected model of teachers' professional growth (Clarke and Hollingsworth, 2002) suggests that teacher learning occurs through the mediating processes of reflection and enactment connecting four distinct domains (situated in the change environment), namely:

- External domain: information, stimulus, and support from external sources;
- Domain of practice: professional experimentation in the classroom;
- Personal domain: teacher's knowledge, beliefs, and attitudes;
- Domain of consequence: salient outcomes.

Collegial interaction is part of the change environment surrounding all the domains, but in other studies collegial interactions are seen as the main field of interest in the domain of consequence (Van Driel and Beijaard, 2003). With learning communities as the focus for much contemporary debate and research more knowledge on collegial interactions is surely needed. However, empirical research looking into the individual teacher's professional learning in collaborative settings is lacking: knowledge regarding teachers' process of developing ideas and understanding while participating in learning communities, how they make use of inputs and how they engage in professional experimentation.

## RESEARCH QUESTIONS

In the context of a collaborative project that uses artifacts from practice in local classrooms to focus on students' thinking and learning in science, the research questions are:

1. How do individual teachers reflect on the project?
  - a) What outcomes do they identify?
  - b) To which aspects of the project do they refer?
2. What links do the teachers make between a) and b), and what insight into their meaning-making do these provide?

## THE LOCAL PD-PROJECT

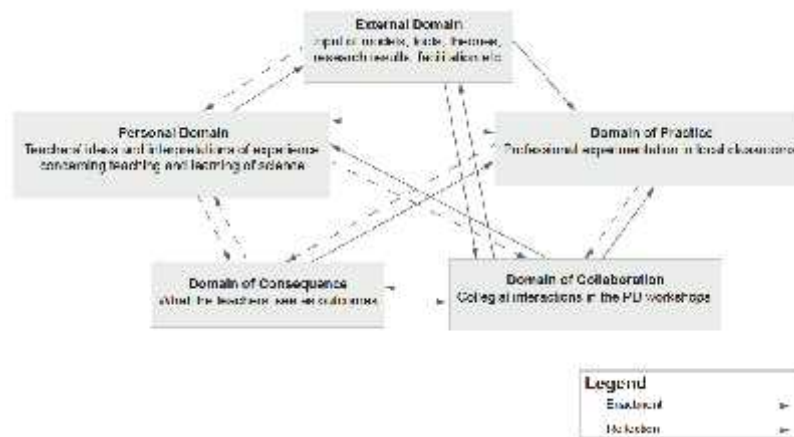
The local PD project being the frame for this research is situated at a school that offers primary and lower secondary-level: grades 1 to 6 are taught integrated Science & Technology, while grades 7 to 9 have separate lessons for Biology, Geography, and Physics & Chemistry. All teachers who teach one of those science subjects are in the science team. Interviews before start of the project indicated considerable variation in the teachers' engagement in cooperation in the team and in developing science teaching locally. The idea to use artifacts from practice, in particular classroom video, to focus on students' learning in science, was presented by the facilitator (and researcher), but the project was situated at the local school and the particular themes raised were decided in the team. Facilitated experimentation with new tools and the collection of video data and other artifacts took during the yearlong project place between a range of half day workshops. Examples of collected artifacts and the work in the workshops are referred to below. The facilitator structured the discussions during the workshops and, when needed, offered input and tools from the knowledge base of research in science education regarding typical student preconceptions and alternative conceptions in science.

## METHODOLOGY

Data were collected through semi-structured interviews. Interviews with participating teachers and the school pedagogical leader before workshop 1 were used to collect background data. Four teachers were then selected for an in-depth study focused on the teacher's science teaching during the project period and the PD experience. Purposive sampling was used to represent different levels of experience and teaching across a range of grades (Cohen et al., 2007). The four teachers were:

- Teacher A: novice teacher in her first year of teaching science, specialized in Science & Technology, teaching Science & Technology in 5<sup>th</sup> grade.
- Teacher B: in her third year of teaching, specialized in Geography, a non-specialist teaching Science & Technology across all 3<sup>rd</sup> grade classes.
- Teacher C: an experienced teacher specialized in Biology, teaching Science & Technology in 6<sup>th</sup> grade, has recently taken a diploma degree in Science Education acting as resource teacher for the science team.
- Teacher D: the most experienced/senior teacher, specialized in Geography, teaching 8<sup>th</sup> grade Geography.

The interconnected model (Clarke and Hollingsworth, 2002) was adapted as analytical model to facilitate analysis and representation of the complex interplays in relation to the teachers' meaning-making. The model was adapted with a new *domain of collaboration* to include the collegial interactions facilitated during the project (Van Driel and Beijaard, 2003) (Fig. 1).



**Fig. 1. Meaning-making model**

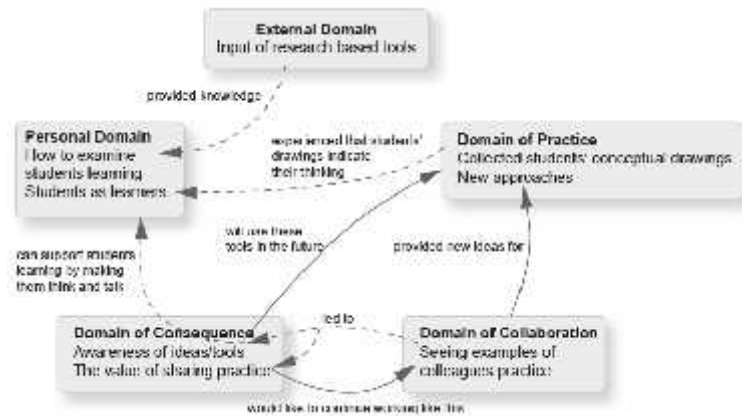
The domains in the model are linked by the arrows reflection and enactment to represent how change in one domain is translated into change in another. When a teacher's reflection involves two domains, a reflection arrow is used between the domains; when the teacher refers to how something in one domain entails something in another domain, an enactment arrow is used. The final representation is called a meaning-making map. Clarke and Hollingsworth (2002) alternate between calling the illustrations change sequences and growth networks when interpreted as more lasting growth. The naming used here emphasizes the research aim: to examine teachers' perceived outcomes and represent their meaning-making.

In the first step of analysis interview transcripts were analyzed to identify utterances relating to each individual domain. In the second step utterances categorized as belonging to more than one domain in the first step were identified and the domains linked by reflection or enactment. For example, when asked about outcomes teacher B refers to her experience of teaching unfamiliar science content: "I think it has been really good teaching this electricity [...] while they simply loved to go to the science-lab and to do those experiments". The teacher reflects on something she sees as an outcome (domain of consequence) and links it to something new she has tried in her class (domain of practice), so a reflective arrow is made. Teacher B continues talking about this, saying that "in discussions in class [...] you could follow how various students [...] caught the point". A reflective arrow between the domain of practice and the personal domain represents her interpretation of experience in relation to students as learners. When referring to her professional work looking forward, she says she wants "to try new approaches in my class, like the one we tried with electricity". An enactment arrow from the domain of consequence to the domain of practice, represents an intention to build on this outcome through further professional experimentation.

The third step of analysis was a process of constant comparison to develop open coding categories that described the content of the of teachers' utterances referring to each domain.

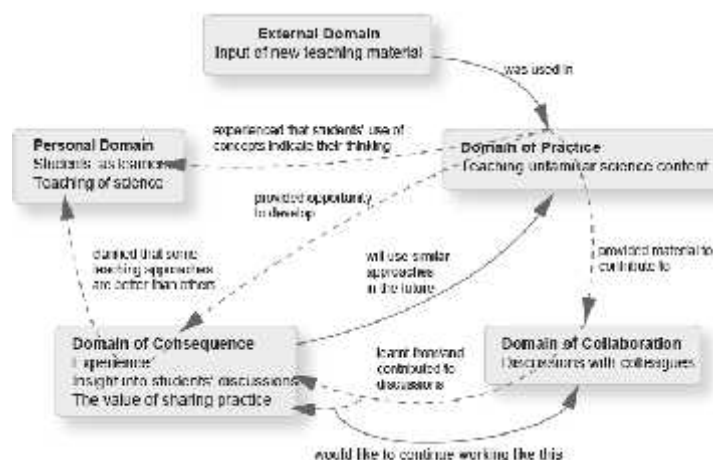
## FINDINGS

Findings will be presented as a meaning-making map and a pen-portrait for each teacher.



**Fig. 2. Meaning-making map teacher A**

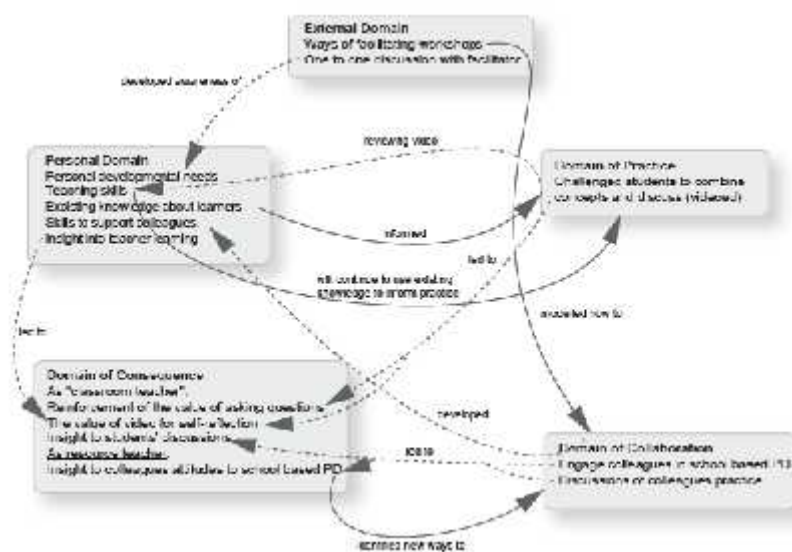
Domain of collaboration can be seen as a key domain to understand teacher A's meaning-making (fig. 2). The inspiration from colleagues is what she emphasizes as the main outcome. She refers to discussions about students' thinking based on video from colleagues' practice and how she became aware of the benefit of using tools like concept cartoons (Keogh and Naylor, 1999). Her emphasis on students talking science is developed along the project. In the first interview she focused very much on hands on activities as an ideal, but she also referred to having problems with classroom management sometimes letting the students do written work instead of experiments. In the second interview her emphasis is more on letting students think and talk than on activities in it-self. During the project she collected drawn and written artifacts to examine her 5<sup>th</sup> grade students' understanding of cardiopulmonary circulation (Domain of practice). The students were asked to draw, in a pre-drawn shading of a body, the processes and functions of human blood circulation, following some lessons in physiology, where they, among other things, dissected the hearts of pigs. The drawings were discussed in one of the workshops. She did not refer to this in the retrospective interview until she was prompted, following her spontaneous reference to what was seen in her colleagues' classrooms. However, when asked what she gained from this experience she reflected on and interpreted the students' drawings, saying "it is clear that they draw the heart and not the lungs [...] getting the lungs in and the two circuits, it was hard for them". She also noticed that the students had a tendency to draw one-way blood circulation out from the heart.



**Fig. 3. Meaning-making map teacher B**

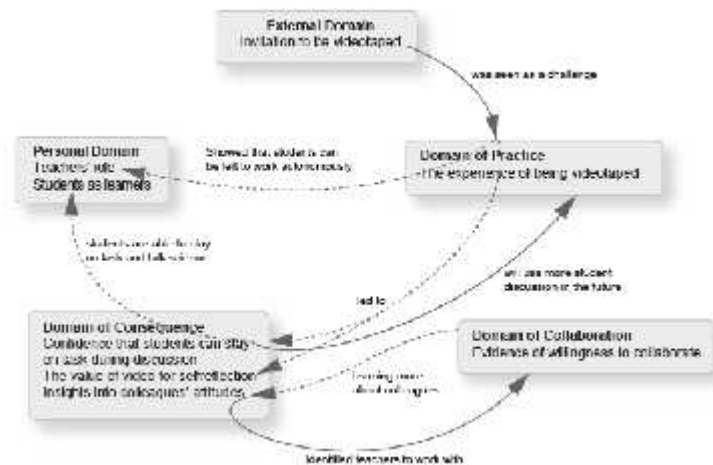
Teacher B taught electrical circuits for the first time during the project (fig 3). In the interview she refers to the teaching material that involved continuing shifts between students posing

hypotheses, their progressing experiments, and class and group discussions. Various artifacts from her 3<sup>rd</sup> graders, including video, were discussed in the workshops. Preconceptions from many 3<sup>rd</sup> graders were identified in relation to only one connection needed from bulb to battery or two ‘arrows’ from the battery meeting in the bulb. After a few lessons all the students referred to circuits and most students specifically attached the wire to two different places on the bulb. The domain of practice can be seen as the key domain in teacher B’s meaning-making map. Nearly all reflections are connected to this positive experience. It seems to have clarified for her that some teaching approaches are better than others. Referring back to an earlier experience at a local resource center, she states that too much emphasis was on ‘science as a show’ compared with the focus on students’ thinking used now. Teacher B also refers to presenting video and other artifacts from her classes in the team. In retrospect, she sees herself as having been passive in the science team before “I didn’t feel it was my field, I do not have very much physics”, but she values being able to contribute in the project.



**Fig. 4. Meaning-making map teacher C**

Teacher C has the most complicated map (fig. 4) as nearly all her considerations involved reflections from being both a resource teacher and a classroom teacher. Her teaching in two 6<sup>th</sup> grade classes involved examining students’ preconceptions and their experiments with simple chemical analysis. The emphasis in the material she used was on the systematic approach, and before doing experiments the students discussed in groups what a criterion is and what classification is. As a resource teacher, she wanted more colleagues to be aware of this approach that she knew from her diploma. She backs her teaching on her existing knowledge about students as learners. Reviewing video informed her own practice; she mentions the value of asking questions instead of just giving answers. The project also informed her as a resource teacher, providing insight into her colleagues’ practice. She reflects on how you “learn as a teacher by seeing/doing it yourself, not just by being told”. In that way the domain of collaboration can be seen as another domain of practice for her. Being a resource teacher can be challenging, and teacher C through the project developed an awareness of personal developmental needs. She refers to one-to-one discussions with the facilitator and to being inspired by the way the workshops were facilitated: “It is good to get this from outside, so I also feel that I get some ‘feedback and support’ [she uses the term “sparring”]”.



**Fig. 5. Meaning-making map teacher D**

During the project teacher D tried a tool inspired by concept cartoons to encourage 8<sup>th</sup> graders' to discuss the earth's climate. The students in groups discussed three suggestions by named imaginary young people. The 8<sup>th</sup> graders were very engaged in the discussion, contrary to what teacher D had expected; she had thought before the lesson that this was 'a piece of cake', as the theme had been taught in 7<sup>th</sup> grade. In a workshop the students' misconceptions, such as distance from the earth as an aspect rather than tilt and angle of incidence, were identified. The video and post-lesson essays from the students revealed how they, through discussion and purposeful questioning from teacher D, developed largely scientifically correct explanations, expressed in their own words. Teacher D's meaning-making map looks very much like teacher B's, but the experience of being videotaped per se is her focus. She does not mention presentation and discussions of video from her class in the workshops as teacher B does; it is her own self-reflection based on the video that she sees as an outcome. She refers to the science team as individuals pulling in various directions, and emphasizes the lack of cooperation between lower secondary science teachers. The project, however, has provided her with evidence of some colleagues' willingness to collaborate.

## DISCUSSION

Teacher A's expressed idea about active self-regulated students seems to create a tension in relation to her coping with classroom management and so does her expressed wish to be able to answer all the students' questions, as she does not feel confident in physics. Novices struggling with classroom management, their activity orientation and low efficacy beliefs in the area of physics, which is also expressed by teacher B, are general challenges among Danish science teachers (Nielsen, 2011). In relation to A's meaning-making the interesting issue is that through her journey in the project she seemed to be in a development. She emphasizes inspiration from colleagues, which help her in the area of tension providing tools to see science as more than students' hands-on activities. Artifacts shared in collegial interactions seem to give her some event-structured knowledge to help see how the input from facilitator and colleagues can be used in concrete classroom situations. It might be that this way she gets ideas and efficacy to experiment more purposefully in her own practice. Teacher B's meaning-making map, her outcomes from experimenting with new approaches, can be seen as a general pattern. It has a close resemblance to patterns in teachers' learning mentioned in previous studies (e.g. Bakkenes et al., 2010). Teacher D's map shows nearly the same pattern and all four maps have reflective arrows between the domain of practice and the personal domain. In spite of local barriers there seems to be a growing awareness among the teachers of how they gain from collaboration for example teacher B when facilitated in

developing her own practice seems to feel she has something to contribute to the team and when this is successful she gains even more confidence.

## CONCLUSIONS AND IMPLICATIONS

The four informants emphasize various outcomes from the project; they seem to follow individual trajectories and in retrospect to identify outcomes connected to current tensions in their professional work. However all the teachers refer to their experiences from experiments in professional practice and reflect on and interpret those experiences in relations to the students' learning of science. In relation to implications for the design of PD, school-based projects give the opportunity for local experiments being shared collaboratively and such facilitated collegial interactions might be needed to acknowledge the value of sharing practice. This might lead to a continual effort to qualify local practice: potential generative development. School-based PD also serves the possibility to acknowledge individual tensions, which in this study has shown to be deterrent in relation to their professional learning.

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# TEACHERS AS *LEARNERS* AND *DESIGNERS* OF ICT-DRIVEN SCIENCE CURRICULUM MATERIALS: FINDINGS FROM THE “ICT FOR INNOVATIVE SCIENCE TEACHERS” PROJECT

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**Abstract:** The purpose of this study was to examine the influence of a professional development course on teachers’ evolved understandings of the ways ICT tools could be integrated in science teaching to scaffold and facilitate the learning process. The participants were nine physics teachers enrolled in 7 two-hour sessions that made use of two ICT tools. The course was organized in two phases. During Phase 1 (“teachers as *learners*”), the teachers were engaged in multiple cycles of data collection and analysis (through data sensing and logging), modeling (e.g., building, refining, testing, and validating models), video analysis, and investigation through the use of simulations. During Phase 2 (“teachers as *designers*”), the teachers re-designed an existing unit from their science curriculum to foster the development of understanding of the unit’s concepts through the use of ICT tools. Data sources included teachers’ responses to a written pre/post questionnaire about their prior teaching experiences with ICT, reflective diaries and teachers’ lesson and unit designs. The findings revealed that the participants expanded their understandings of the various ways that ICT tools can be integrated within science instruction and they also shifted from the “authoritarian” model that dominated the majority of their initial designs to a more student centered approach through which the students use ICT tools for sense making, exploration, and knowledge construction. Additionally, modeling activities were very limited within teachers’ revised lesson designs or totally omitted from their reconstructed units, a finding that points to teachers’ inadequacy to develop epistemic awareness with respect to the purpose and the role of models and modeling in science teaching and learning. The paper concludes with a discussion of the relevant professional development issues and a set of recommendations about the underpinnings of ICT professional development courses.

**Keywords:** teacher professional development, ICT-enhanced teaching and learning, teacher understanding of ICT usage

## THEORETICAL BACKGROUND

Although reform documents call for the integration of ICT tools in science teaching, it has been reported that teachers appear to have difficulty with creating classroom environments in which students are supported in creating their own constructions of knowledge through the use of ICT tools (Koehler, Mishra, & Yahya, 2007). A major factor that contributes to teachers’ struggles with integrating technology into their teaching in a constructivist way relates to the absence of a theoretical framework from training seminars or professional development programs that guides the nature of technology integration into teacher learning (Hughes, 2004). As a result, ICT courses and workshops frequently tend to focus on providing teachers with technical skills necessary for operating the hardware and software (Kennewell, 2001; Zhao et al., 2002), and leave aside the pedagogical underpinnings behind the technological integration in science teaching and learning.

If we anticipate from teachers to become “technology integrationists” (Hughes, 2004), then teacher professional growth programs should aim to “... change teachers to teachers as active learners [by] shaping their professional growth through reflective participation in

professional development programs and in practice” (Clarke & Hollingsworth, 2002, p. 948). Advocates of the *teacher as learner* approach emphasized the importance of designing professional development courses through which teachers should be offered “...opportunities for learning from teaching, rather than learning of teaching” (de Jong, van Driel & Verloop, 2005, p. 6). This *teacher as learner* approach moves beyond the traditional teacher preparation tradition through which teachers learn how to write good lesson plans or act as (passive) receivers of information about the various strategies of how to teach, as it places the teacher directly in the role of inquirer in simulated research experiences.

It is also equivalently important to give teachers the authority to act as designers of their own ICT-driven science curriculum materials, because engaging teachers in constructing a public artifact (e.g., their own curriculum) is a productive way to support their learning (Papert, 1991) and the transformation of their personal learning experiences into pedagogically potent curriculum designs. Teachers should take the role of active participants in any implementation or instructional reform we seek to achieve, and thus we need to offer them a certain degree of autonomy and power in making pedagogical decisions while designing and implementing their own curriculum (Mishra & Koehler, 2006). The idea of *teachers as curriculum designers* is based on the stance that teachers are “an integral part of the curriculum constructed and enacted in classrooms” (Clandinin & Connelly, 1992 p. 363), since their effort of curriculum development undergoes an organic process of iterative design, refinement and negotiation of a balance between technology, pedagogy, and content (Mishra & Koehler, 2006).

## PURPOSE AND RESEARCH QUESTIONS

Grounded on the tenets of the *teacher as learner* and *curriculum designer* perspective described above, the purpose of this study was to examine the influence of a Professional Development Course (PDC) on the development of teachers’ informed understandings about the various ways that ICT tools could be integrated in science teaching to scaffold and facilitate the learning process. Specifically, the two research questions that this study aimed to address were as follows: (1) *What did teachers’ learn in terms of (i) how ICT tools are integrated in science teaching and (ii) the role of ICT tools in science teaching, as a result of their participation in the PDC?*; and (2) *How did teachers’ ICT-driven lesson designs change as a result of their participation in the PDC?*

## METHODS

### Participants and Setting

The participants were nine physics teachers (7 males, 2 females) enrolled in a Professional Development science education Course (henceforth called PDC) that made use of two types of software, namely “Data-logging Insight” and “Coach 6”. Five of them held a master degree in physics and all of them were at the time carrying a full teaching load. None of them had participated before in a course on how ICT can be integrated within science instruction.

The course was organized in two consecutive phases. During Phase 1 (“teachers as learners”), curriculum materials that were developed in the contexts of “Change of State” and “Forces and Motion” were implemented through which teachers were engaged in multiple cycles of data collection (through data sensing and logging), data analysis, modeling (e.g., building, refining, testing, and validating models), video analysis, and investigation through the use of simulations. After every session, the participants were asked to write reflective journals about their experiences and knowledge gained about the use of ICT tools in each session. During Phase 2 (“teachers as *designers* of ICT- driven curriculum materials”), the

teachers were asked to reconstruct a unit from the school curriculum to foster the development of understanding of the unit's concepts through the use of ICT tools. As part of the requirements for their curriculum designs, teachers were asked to: (i) formulate learning objectives, (ii) provide descriptions of the design and the implementation of each activity, (iii) design activity sheets based on their activities' descriptions, and (v) design assessment tasks to evaluate their learning objectives.

### Data collection and analysis

We collected multiple forms of data throughout the course; (i) teachers' responses to a written questionnaire about their beliefs and attitudes concerning the role of ICT in their teaching, and their knowledge and prior experiences regarding the use of data logging, modeling and video measurement software tools; (ii) teachers' initial and revised lesson designs that illustrate the use and role of ICT tools; (iii) teachers' reflective journals; and (iv) teachers' reconstructed units. The data were analyzed quantitatively using descriptive statistics and qualitatively using an open coding scheme refined through the use of the constant comparative method (Glaser & Strauss, 1967).

### FINDINGS

*What did teachers' learn in terms of (i) how ICT tools are integrated in science teaching and (ii) the role of ICT tools in science teaching, as a result of their participation in the PDC?*

The analysis of the data collected from questionnaires that were administered at the beginning of the course, revealed that the participants had a very limited understanding of the ways that ICT tools can be integrated within science instruction to facilitate the learning process, as they stated that the teacher was the one that makes use of ICT tools and the ICT tools were used mostly for demonstration purposes within a science lesson. Evidence from teachers' reflective diaries during the course indicates that the types of activities that they were engaged with enabled them to expand their understanding of the various ways that ICT tools can be integrated within science instruction and they also appeared to have appreciated the multiple learning benefits from such integration. Specifically, the majority of teachers reported that throughout the course they learned how to analyse data with the use of specific software, identified advantages of the use of ICT in relation to the collection of more accurate measurements and performance of easier and faster data analysis, and appreciated the role of ICT in promoting students' interest towards science.

Apart from evaluating teachers' learning about the use, the role and contribution of ICT tools in relation to teaching and learning, we also examined teachers' evolved understandings about models and modeling, since they were engaged with modeling activities within the PDC. We summarize the findings from teachers' understanding of the nature of models and modeling in Tables 1 and 2 respectively.

Table 1. Teachers' understanding of the nature of models prior to and after the PDC

Category of response	Prior to the PDC	After the PDC
A model is ...		
...a mathematical expression of a theory	1	-
...a specific environment for simulating or studying a phenomenon	1	3
...a construct (e.g., an apparatus, an algorithm) that we use to study a phenomenon	2	-
I don't know this term	5	-

<i>...a set of mathematical equations that strengthen the description of a phenomenon</i>	-	2
<i>... is a program that runs on the computer and substitutes the experimental procedure. It produces error-free measurements and hence it helps in our understanding of the natural phenomenon</i>	-	2
<i>... the representation of a phenomenon with the use of a software. It needs to represent the phenomenon under study, provide a mechanism that explains how the phenomenon functions, and enable the formulation and testing of predictions</i>	-	2

Table 2. Teachers' understanding of the nature of modeling prior to and after the PDC

Category of response	Prior to the PDC	After the PDC
Modeling is ...		
<i>..the simulation of natural phenomena in a specific environment</i>	3	2
<i>..a number of equations through which natural states are simulated in a way that information of how a phenomenon functions can be achieved</i>	2	-
<i>.. ..the process through which our understanding about how a phenomenon functions is represented in a model</i>	1	1
<i>..the use of a model from a theory to study a phenomenon</i>	1	1
<i>..the creation of a standard frame for studying a phenomenon</i>	1	
<i>..the creation of an artificial environment (or a simulation) for studying a phenomenon</i>	1	4
<i>..the creation of a model after observing a phenomenon. Next, the model can be improved through comparing it with the physical phenomenon. The model needs to represent the phenomenon and enable the testing of predictions. In case the model fails to fulfill these criteria, we need to return to the initial stage of modeling and revise the model accordingly</i>	-	1

The findings reported in Tables 1 and 2 indicate that the participating teachers failed in making a substantial shift from their naïve conceptions expressed prior to the PDC to more sophisticated understandings of the nature of models and modeling. Although prior to the PDC the majority of the teachers were unfamiliar with the concept of “model”, after the PDC seemed to have associated this concept with the software that was used for creating a model or simulating a phenomenon. In other words, they appeared to have conceived the models as technical tools and not as representational tools that facilitate our understanding about the underlying mechanisms of the phenomena being modelled. Likewise, the majority of the teachers after the PDC stated that modeling concerns the creation of an artificial environment or a simulation, a view that demonstrates their failure to conceive modeling as a process of developing and deploying models that account to our observations and serve as means to facilitate our understanding of a phenomenon.

#### *How did teachers' ICT-driven lesson designs change as a result of their participation in the PDC?*

The analysis of teachers' initial and revised lesson designs and the unit that they reconstructed was centered around the types of ICT that teachers chose to incorporate within their lesson designs, the role of the ICT tools in relation to the teaching and learning and the ways that the ICT tools were used to scaffold the learning process. We summarize the findings from this analysis in Table 3.

Table 3. Types of ICT tools and ICT-driven activities within teachers' initial and revised lesson designs and reconstructed unit

Type of ICT-driven activity	Prevalence of each type of activity within the ...		
	initial lesson design	revised lesson design	unit reconstruction
1. The teacher uses videos for demonstration purposes at the beginning of lesson to stimulate students' interest	4	3	2
2. The teacher presents pictures through a projector connected to a computer at the beginning of the lesson to stimulate students' interest	3	0	1
3. The teacher shows a simulation of a phenomenon under study to the students	3	5	2
4. The teacher uses sensors to collect data from an experiment s/he performs	3	0	1
5. The teacher presents graphs developed in a software of the data collected from an experiment	1	0	0
6. The students work in groups and use ICT for data logging and data analysis	2	7	8
7. The students work in groups and investigate a phenomenon through a simulation	0	2	2
8. The students work in groups and use a modeling tool to construct a model of a phenomenon under study	0	2	0
9. The students work in groups and use a video analysis software of a phenomenon under study	0	1	1

The findings reported in Table 3 indicate that at the beginning of the course the majority of teachers chose the use of ICT for demonstration purposes (see types of activities 1, 2 and 5 in Table 3). Even in the case of integration of a simulation within the initial lesson design (see type of activity 3 in Table 3), the way that the simulation was suggested for use was again for demonstration purposes and not for the investigation of a phenomenon through the manipulation of the variables of the simulation. This type of ICT use was consistent with teachers' prior experiences and knowledge that were reported in the questionnaire prior to the PDC and presented in the previous section of the Findings.

Another interesting finding that was revealed from the data collected for answering the second research question and merits attention relates to "who" will be using the ICT tools during the implementation of the lesson design. All but two teachers described that they themselves would use the ICT tools and not the students. Hence, we might assume that the teachers prior to the PDC felt that either the ICT is a powerful tool that is used only by the teacher who is willing to make her instruction more interesting and compelling or that their students would not be able to use the ICT tools appropriately due to lack of skills on how to use them or that the ICT tools could not be used as learning tools to enhance students conceptual understanding or the development of reasoning skills.

Evidence from the analysis of teachers' revised lesson designs and the unit that they reconstructed revealed that, after the course, the teachers shifted from the "authoritarian" model that dominated the majority of their initial designs to a more student-centered approach (see types of activities 6 through 9 in Table 3) through which the students use ICT tools for sense making, exploration, and knowledge construction. Specifically, after the course the majority of teachers suggested that they would organize their students to work in groups and they would let their students to use the ICT for data logging and data analysis.

However, modeling activities were very limited within teachers' revised lesson designs or totally omitted from their reconstructed units, although they engaged in several modeling

activities during the PDC. A possible explanation that accounts for this failure might relate to teachers' inadequacy to develop epistemic awareness with respect to the purpose and the role of models and modeling in science teaching and learning, as it has already reported in the findings presented for research question 1.

## CONCLUSIONS AND IMPLICATIONS

In this study we aimed to explore whether a Professional Development Course (PDC) that builds upon the premises of teachers as *learners* (Clarke & Hollingsworth, 2002; de Jong, van Driel & Verloop, 2005) and teachers as *curriculum designers* (Mishra & Coehler, 2002) could impact on the development of teachers' informed understandings about the various ways that ICT tools could be integrated in science teaching to scaffold and facilitate the learning process. The findings revealed that during the PDC the participants expanded their understandings of the various ways that ICT tools can be integrated within science instruction and they also shifted from the "authoritarian" model that dominated the majority of their initial designs to a more student centered approach through which the students use ICT tools for sense making, exploration, and knowledge construction. We believe that by allowing teachers to design their own curriculum materials, we offered them opportunities to think of issues like "How does ICT-driven instruction look like in practice?" or "What do I expect from my students to develop during their engagement with ICT-driven activities?" Hence, we argue that without teachers' personal involvement in developing these materials, the understanding of the role of ICT tools in science teaching and learning, to the extent that appeared to occur because of their personal involvement, would not be possible.

However, the participating teachers seemed to have not developed informed understandings about the nature and the role of models and modeling since the modeling activities were limited within teachers' revised lesson designs or totally omitted from their reconstructed units. A possible explanation that accounts for this failure might relate to teachers' inadequacy to develop epistemic awareness with respect to the purpose and the role of models and modeling in science teaching and learning. This finding is in line with what Justi and van Driel (2005) found in their study, as they reported that even though teachers received information about how to integrate modeling principles in their science instruction, they were neither became committed to such approaches nor felt that their instruction would be more effective and productive by applying them. Consequently, we suggest two important revisions/additions to the format of our PDC in order to succeed on helping teachers to design and implement modeling-based activities for their future implementations. We elaborate on these suggestions in the following sections.

The first revision we would like to suggest relates to the design of extra activities during the first phase of our PDC (Teachers as Learners) that would engage the participants in more explicit epistemological discourse about models and modeling. For instance, after the teachers develop a model about a phenomenon they observe, it is important to prompt them to reflect on (i) the procedure they followed for developing their model (e.g., did they follow a linear procedure or a cyclical one? what were the several phases they went through for developing their model and what did they do during each phase?), (ii) the nature of their model (e.g., what aspects from the phenomenon are represented within their model and why did they choose these aspects to incorporate to their model), (iii) the criteria they should use for evaluating their model (e.g., representational coherence, explanatory power, and predictability), (iv) the role of creating models within science instruction and in science in general. By engaging teachers in the abovementioned epistemologically oriented activities, we expect that the teachers will develop epistemological awareness about models and modeling and thus they would think of similar activities when they will design their own curriculum materials.

The second and more major revision we suggest concerns the addition of an intermediate phase between Phase 1 (Teachers as Learners) and Phase 2 (Teachers as Curriculum Designers) through which teachers as curriculum thinkers this time, would engage in several reflective activities through which they will be given the opportunity to view and analyse ICT-driven curriculum materials from a pedagogical and instructional perspective. For instance, we propose that this new phase would engage teachers in the study of the underlying pedagogical and technological underpinnings of the curriculum that were engaged with during acting as learners or other ICT-driven curricula. Several prompts for reflection (e.g., *What learning objectives are promoted through each activity? How the development of conceptual understanding is promoted in the curriculum? What is the role and contribution of a specific ICT tool in the curriculum? What is the added value that the ICT tools bring in the curriculum?*) would be added in order to scaffold teachers' thinking. Some representative reflective prompts are as follows:

In summary, we conjecture that any professional development course that aims to help teachers to become effective technology "integrationists" should give emphasis on the development of their ability to (i) understand, consider, and choose to use technologies only when they uniquely enhance the curriculum, instruction, and students' learning, and (ii) to interpret new technology concepts through their professional knowledge – the knowledge that both consciously and subconsciously directs their daily teaching activities (Hughes, 2004). As a result, teachers are anticipated to use their general pedagogical knowledge, subject matter knowledge, and pedagogical content knowledge (Shulman, 1987) to identify promising, innovative ways that technologies may be used to teach their subject area (Margerum-Leys & Marx, 2002).

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## **PRE-SERVICE PHYSICS TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE IN DIFFERENT TEACHER EDUCATION PROGRAMS**

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*Abstract:* The current discussion about the reorganization of teacher education programs resulted in a rising interest in (physics-) teachers' professional knowledge. This field, however, lacks empirical research concerning the professional development within the university part of teacher education programs. Against this background, a paper-and-pencil-test was developed to measure different aspects of professional competence including pedagogical content knowledge (PCK). Based on a measurement of competence in a group of 430 students in lower and upper secondary level teacher education programs, our study compares those different programs in order to determine their efficacy. Furthermore, our study presents results concerning the development of physics student teachers' PCK and its interplay with other domains of professional competence. In this context, the duration of the education, the amount of CK and the final school exam grade were identified as relevant predictors of students' PCK. Additionally, conclusions are drawn concerning the validity of the test approach. Apart from several pilot studies, a specific study is conducted to validate the paper-and-pencil-test regarding beginning teachers' action competence. Therefore a video based instrument was developed to measure science teachers' quality of performance in real classroom situations.

*Key words:* PCK, teacher education, professional competence, physics

### **PROBLEM DEFINITION**

In recent years, unexpected and disappointing results of large scale assessments like PISA and TIMSS have led to a broad discussion about reasons and necessary changes of science education in Germany. The assumption that science teachers do not acquire sufficient competencies and skills for "high quality" instruction within their teacher education programs causes a rising interest in what are important aspects of – especially physics – teachers' professional competencies and in how these are implemented in education programs. Despite of many interesting approaches and projects, there is still a lack of empirical research findings concerning these questions. Up to now it is unclear to which extent needed competencies and skills are acquired and what their development is like especially in the pre-service phase of teacher education.

In the area of Physics, this study exemplarily shows a possible procedure how to operationalize pre-service teachers' pedagogical content knowledge (PCK) and how to develop corresponding instruments according to theoretical principles. Furthermore, a specific study is conducted to validate the paper-and-pencil-test regarding trainee teachers' action competence. Therefore a video based instrument was developed to measure science teachers' quality of acting in real classroom situations.



## Physics Teacher Education in Germany

German teacher education programs are highly variable between different federal states. Nevertheless they have a common general structure. A first academic phase of teacher education with a duration of three or four years is followed by a one to two years lasting practical phase of in-service teacher training. In most federal states there are two different physics teacher education programs for secondary level schools, which emphasize different aspects of science instruction according to different school types and mainly vary in the “depth” of the implemented content knowledge in physics. According to this, differences concerning the acquired competencies in these two education programs can be expected.

## Objectives

To get findings regarding the outcomes of different physics teacher education programs, this study aims on three main objectives. First (1) a model of pre-service teachers’ professional action competence has to be conceptualized. In a second step (2), a quantitative instrument to measure different aspects of this competence has to be developed, piloted and validated, which can be used to analyze (3) the development of pre-service physics teachers’ professional action competence in lower and upper secondary level teacher education programs.

## THEORETICAL FRAMEWORK

### Professional Action Competence

Summarizing the findings in the domain of investigating the efficacy of teacher training, Baumert & Kunter (2006) developed a heuristic model of professional action competence (fig. 1).

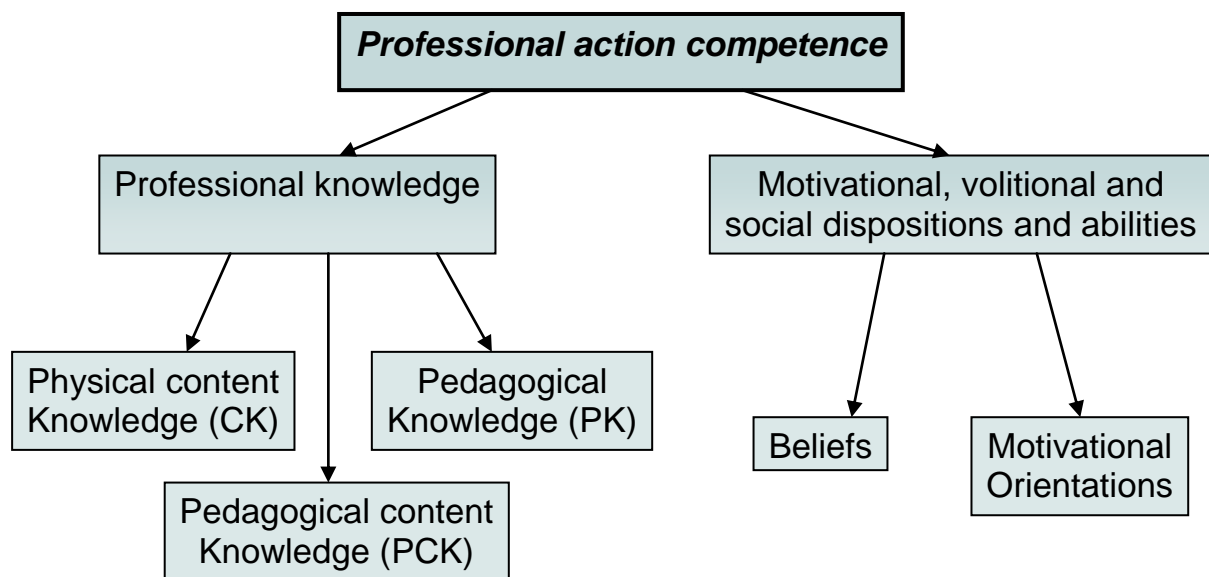


Figure 1 “Heuristic model of teachers’ professional action competence”

At the core, the model draws on Weinert's (2001) conceptual classification of the concept of competence to characterize the structure and development of teachers' professional competence. Thus, competencies refer to necessary prerequisites that have to be available for successfully meeting complex demands in a specific domain. Against this background, one aspect of professional competence reported in the literature is professional knowledge. According to a classification established by Shulman (1986) and widened by Bromme (1992), three aspects of teachers' professional knowledge can be identified: content knowledge (CK), pedagogical content knowledge (PCK) and pedagogic-psychological knowledge (PK). Furthermore, it has to be considered that professional action competence, beside theoretical skills and knowledge, also comprises practical skills and knowledge up to the development of patterns of acting (Fenstermacher, 1994). Although there are further components of teachers' professional competence like beliefs and personality factors (Jones & Carter, 2007), this article concentrates on the operationalization of PCK.

## **Pedagogical Content Knowledge**

Shulman defines pedagogical content knowledge as a specific type of knowledge of professionals in the field of teaching and includes "the most useful forms of presentation of contents, the most powerful analogies, illustrations, examples, explanations and demonstrations [...], the way of representing and formulating a subject that make it comprehensible to others" (Shulman, 1986, p.9f). Besides several other aspects, PCK also includes knowledge about typical difficulties in teaching a specific topic and especially students pre- and misconceptions. Shulman's concept of PCK formulated a base for various research projects in the field of teacher education and therefore was often widened, reconceptualized or adopted in many different ways. According to Lee & Luft (2008), the following dimensions of PCK can be formulated: subject matter, representation and instructional strategies, student learning and conceptions, general pedagogy, curriculum and media, context, purpose and assessment. To investigate education programs for pre-service physics teachers, these aspects of PCK have to be concretized according to the domain of physics.

## **OPERATIONALIZATION OF PCK**

Because of limited time while surveying those different aspects of pre-service physics teachers' competence, there is a focus on the role of experiments as a specific type of physics instruction on the one hand and student misconceptions regarding the domain of mechanics on the other hand. The former decision is well-founded due to the importance of experiments in physics instruction. It has been observed that about 60 % time of a normal German physics lesson is related to experimenting (Tesch, 2005).

To make sure that all relevant aspects of competence are represented by tasks within the developed instrument, a framework of PCK in the domain of physics was designed while using normative models in terms of teaching physics on the one hand and observations of instructing-practice (e.g. best-practice-examples in video-based studies) on the other hand. So a best possible practice, based on teaching-related demands, is our starting-point. By applying these findings, the following relevant facets were identified: Knowledge about general aspects of learning physics, knowledge about a proper use of experiments, arrangements of learning processes, assessment and reflection of learning processes and finally an adequate reaction in critical situations in physics instruction. In these aspects a hierarchical progression from

rather declarative aspects of PCK (*knowing that*) to rather procedural aspects of PCK (*knowing how*) can be seen (fig. 2).

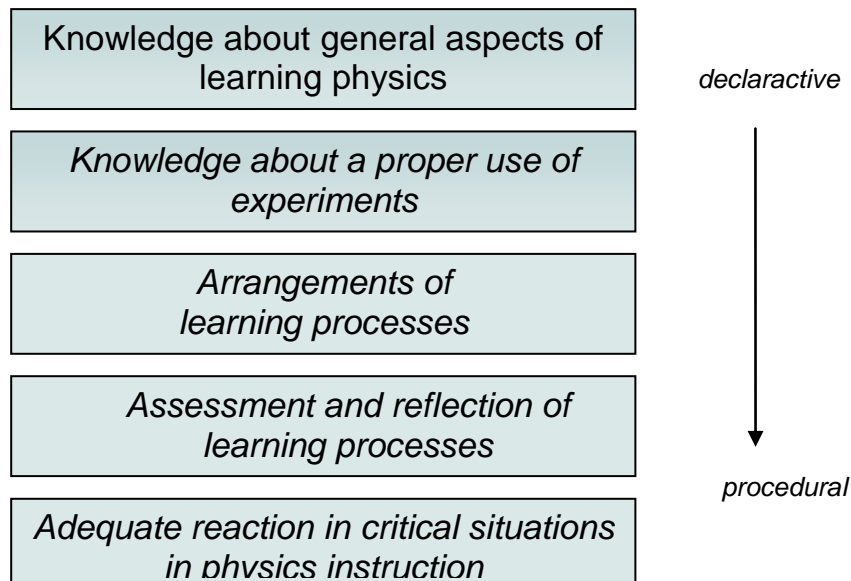


Figure 2 “Operationalization of PCK in physics”

## METHODS

After concretizing the general structure of competence and the operationalizations of the diverse components of teachers’ professional competence, items for a questionnaire instrument were constructed to evaluate CK, PCK, PK, beliefs, attitudes and personality factors. To make sure that the instrument also assesses the (student) teacher’s ability to integrate, to associate and to apply the different components of competence, a pool of teaching-vignettes was developed. Teaching-vignettes are specific critical situations in the context of physics-lessons presented in the instrument, where the surveyed physics student teachers have to analyze the scene, to detect student misconceptions and to make a suggestion of how to continue in a reasonable way.

This instrument was piloted in a group of  $N = 45$  physics student teachers attending one university. Afterwards the items were analyzed via descriptive statistics and factor analysis. Based on these analyses, the instrument was revised to get an empirically meaningful basis for further procedure. After that, the operationalization and parts of the questionnaire like the teaching-vignettes were validated by interviewing experts like experienced teachers, teacher trainers and academic physics educators. In doing so, the experts had to assess the critical situations with regard to relevance in respect of content and representativeness in a first step, and then they had to specify and categorize the tasks and problems. Finally, they had to explain how they would react in such situations in order to get adequate options for action within the sample solution. Moreover, the interviews were used to get further information to specify our model of professional competence of pre-service physics teachers. The once more adapted instrument was piloted in a group of  $N = 55$  physics student teachers, now attending four different universities.

The main study was executed with about 430 students in lower and upper secondary level teacher education programs in several German federal states. For further validation, in a following study trainee teachers are investigated in order to explore to what extend components of their professional knowledge are related to distinct attributes of the quality of instruction regarding their classroom performance. While using the piloted questionnaire to assess their professional knowledge, a specific lesson (introduction of the force-concept in physics) are videotaped and analyzed regarding six main attributes of teaching quality in science instruction: coherent structuring, cognitive activation, motivational encouragement, scaffolding, classroom management and adequate use of experiments.

## RESULTS

### Psychometric Properties

After those steps of piloting the instrument, that was developed to survey physics student teachers' professional competence (see above), a well-working instrument is available now. The test's component related to teachers' PCK consisting of 39 items has a reliability of Cronbach's  $\alpha = 0.74$ . Furthermore the shapes of the distributions concerning the test-persons' total score as well as the items' difficulties (fig. 3) imply that the instrument is neither too difficult nor too easy and that there is enough variance in the data.

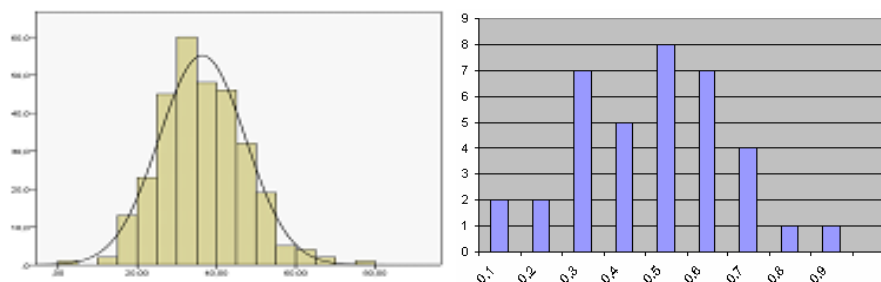


Figure 3 “Histograms referring to the relative total score in PCK (left) and the items' difficulties (right)”

In order to ensure the objectivity of the instrument, coding manuals with solutions based on literature as well as based on statements of experts (see above) were created. We found a good interrater-reliability randomly measured by intra-class-correlation ( $ICC = .91$ ;  $F(25,25) = 20.94$ ;  $p < .001$ ).

We also carried out a criterion-related validation by comparing groups with different expertise levels (students, trainee teachers, teacher trainers) where we found increasing test scores for groups with greater expertise ( $ANOVA F(2, 72) = 7.35$ ,  $p = .001$ ). Finally, we tried to guarantee the construct validity by a combined data-collection with an independently developed instrument (Olszewski, 2010). We found a correlation between the two corresponding PCK-scores ( $r = 0.64$ ) that was higher than the correlation of our PCK-part with our CK ( $r = 0.45$ ) respectively our PK-part ( $r = 0.49$ ) (fig.4). These correlations might indicate that PCK has a kind of middle-position between CK and PK and that CK and PK are prerequisites regarding PCK.

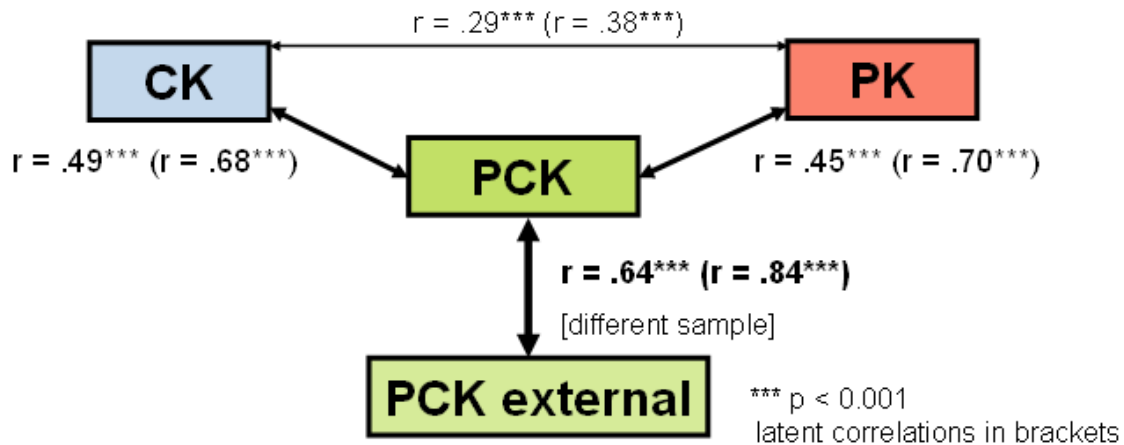


Figure 4 “Correlations within professional knowledge”

### Comparison of different teacher education programs

In a first step, our study compares lower and upper secondary level teacher education programs. In a group of students within their last chapter of the academic study, we found significantly higher PCK-scores in upper secondary level programs compared with students in lower secondary level teacher education programs ( $p^* < 0.001$ ) (tab. 1).

education program professional knowledge	lower secondary level ( $N = 69$ )		upper secondary level ( $N = 69$ )		difference LL, UL	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	diff. $M_{LL}, M_{UL}$	$d_{LL,UL}$
CK	94.4	16.7	109.1	23.6	14.7 ***	.7
PCK	94.3	17.3	105.4	21.4	11.1 **	.6

Table 1 “CK- &amp; PCK-Scores at the end of the academic part of teacher education”

Analyzing the reasons for this, we used a regression analysis to get findings concerning the development of physics student teachers' PCK. In this context, we found that the duration of corresponding parts of the education, respectively the amount of contact hours per week per semester, was identified as a significant predictor of students' PCK ( $\beta = 0.15$ ,  $p = 0.002$ ). This indicates that the lower secondary teacher education program is too short to bring out well trained teachers. Furthermore, the score of CK ( $\beta = 0.38$ ,  $p < 0.001$ ) and the final school exam grade ( $\beta = 0.17$ ,  $p = 0.001$ ) were further relevant predictors. In contrast, the total score in PCK doesn't correlate with the number of corresponding college courses taken, which was used to measure knowledge in the past (cf. Abell, 2007). Apart from this, the number of semesters, the number of practical courses and student teachers' gender were also no significant predictors regarding the score of PCK.

### PCK and classroom performance

Concerning the relation between professional knowledge and classroom performance, very first results are available. In a pilot study, lessons of four trainee teachers and five student teachers were videotaped and the questionnaire instrument was used, too. The lessons were analyzed regarding six main attributes of teaching quality in science instruction coherent

structuring, cognitive activation, motivational encouragement, scaffolding, classroom management and adequate use of experiments. Therefore high-inferent ratings of the teachers' actions in the classroom were carried out for every single attribute using four-point-likert-scales.

Rank correlations (*Kendall's Tau*) between the total PCK-Scores (N=9) and the ratings (on a scale from 1 to 4) show no significant correlation (as expected due to the small sample) (tab. 2). But there seems to be a tendency for a correlation between a teachers' performance concerning the cognitive activation of students in the classroom and the acquired pedagogical content knowledge (cf. Olszewski, 2010).

	<i>Motivational encourage- ment.</i>	<i>Cognitive activation</i>	<i>Coherent structuring</i>	<i>Scaffolding</i>	<i>Classroom management</i>	<i>Use of experiments</i>
<i>PCK</i>	.141	.310	.171	-.141	.085	.059

Table 2 „Rank Correlations between attributes of teaching quality and total PCK-Score”

But these results lacks validity as the comparability of the videotaped lessons is not sufficient because the student teachers mostly did not perform an introduction in the force concept.

## CONCLUSION AND IMPLICATIONS

In view of the current discussion with regard to a reorganization of the first phase of teacher education, our study provides a statistically well working instrument to measure different aspects of physics student teachers' professional competence including PCK based on a theoretical model of competence. Surveying students of different teacher education programs, we are able to identify shortcomings and therewith potential improvements in the process of upcoming pre-service teacher education reforms. At the moment, our instrument is validated with regard to high-quality instruction by analyzing physics lessons in a standardized setting (introduction of force concept). After the data collection of the corresponding video study is completed, further in-depth analyses will allow detailed findings concerning the interplay of the different components of PCK (measured by the paper-and-pencil-test) and physics teachers' quality of acting in real classroom situations.

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# TEACHERS' VIEWS ABOUT PRACTICAL WORK IN UPPER PRIMARY AND LOWER SECONDARY SCHOOL: ANALYSIS FROM A MODEL BASED INQUIRY PERSPECTIVE

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*Abstract:* Despite the important role that science education seems to give to practical work, research has reported during years a lack of effectiveness of the approaches implemented in the science classroom. The research presented in this paper proposes a model-based inquiry framework<sup>1</sup> for practical work and uses this framework to analyze teachers' views about it. These views are obtained by analyzing personal interviews on both teachers' perceptions and reports of practice, including the analysis of teachers' actual designs of practical work activities. From this analysis, some profiles are identified. Our first results indicate that, in general, practical work seems to be important for teachers despite the existing didactical approaches to it are quite traditional. Nevertheless, some of them are interesting to be taken into account as a possible point of departure for a model-based inquiry approach to science teaching and learning, bearing in mind the facilitators and limitations encountered by teachers identified in the analysis carried out.

*Keywords:* practical work, inquiry based science education, model based inquiry

## INTRODUCTION

The interest of this research emerges from the results obtained within the research done during the first phase of TRACES<sup>2</sup> project, where a sample of n= 207 primary and secondary school teachers' answered a questionnaire related to their views regarding effective science teaching. First analysis highlighted the important role given to practical work, but also suggested the existence of a broad range of perspectives regarding its approach with some differences between primary and secondary school teachers' views.

In the light of these first results and considering the authors' interest on model based inquiry science education, the designed research was addressed to answer the question: *Which are teachers' views in upper primary and lower secondary regarding practical work and how these views can foster or hinder a model based inquiry science education?* This research then pretends to enlighten the research findings about practical work in the science classroom from the perspective of one of the didactical approaches that are being supported by the science education research community. To do so, the proposed research has three objectives: to propose a framework for practical work from a model-based inquiry perspective; to characterize upper primary and lower secondary school teachers' views regarding this framework; and to identify possible differences and similarities between primary and secondary school teachers' views from this specific teaching and learning perspective.

## THEORETICAL FRAMEWORK

### Practical work in science education

Practical work is usually considered as a quality indicator for science education. According to some authors it can facilitate the learning of some important scientific procedures such as observation, hypothesis proposals or the analysis and interpretation of results and can help



students to elaborate an appropriate image of scientific activity (Hodson, 1994). In spite of its potential, however, analysis of the practical work being traditionally carried out in school has pointed out a general tendency of practical work to be ill-conceived, confused, unproductive and lacking in educative value (Hodson, 1994). Due to this mismatch between what would be expected and what is actually carried out in schools, research has devoted a lot of effort in trying to clarify which should be the main objectives of practical work. Last studies conclude that these objectives are to develop in students: manipulative and observational skills, the ability to interpret experimental data and to plan experiments, the interest in the subject and a feeling of reality regarding the phenomena being studied in theory (Johnstone & Al-Shuaili, 2001).

For some authors, it is the last point mentioned which constitutes the main purpose of practical work that is to help students to link the real world of objects, materials and events with the more abstract world of ideas and theories (Tiberghien, 2000). Unfortunately, some research results show that there are few evidences about the inclusion of this purpose in the practical work designed by teachers.

### **Model-based inquiry as a didactical approach**

Research seems to confirm, despite the lack of existence of definitive results regarding it, that teaching and learning approaches centered on learning by inquiry (Inquiry-Based Science Education or IBSE) produce positive results related to students' motivation and science learning (Minner et al., 2010). In this sense, there is a general consensus in the literature that IBSE is central for science education (Barrow, 2006), despite claims about IBSE not being the only strategy to be used in the classroom and possibly not an approach to learn all sorts of scientific contents.

Beyond these considerations, research reports a lack of agreement about what IBSE is referred to. In our study we will be based on the literature review made by Barrow (Barrow, 2006) to define the dimensions that characterize IBSE: a) the cognitive abilities that students must develop; b) an understanding of methods used by scientists to search for answers for their research questions; and c) a variety of teaching strategies that help students to develop their abilities of inquiry (a), learn about scientific inquiry (b), and understand science concepts. Regarding them, there is more research consensus regarding what has to be taught to students than how teachers should teach from an IBSE approach (Anderson, 2007). In last years, research has been focused on the dynamics of IBSE and how to bring it to the classroom because despite research has confirmed the feasibility of bringing this approach to science classrooms there are a lot of studies confirming that this approach has not reached yet the expected quality levels. Barriers, external and internal, have been identified when trying to bring IBSE to the actual classroom practices (Barrow, 2006).

Based on the National Science Education Standards of the NRC five essential characteristics are highlighted: 1) scientifically oriented questions that will engage the students; 2) evidence collected by students that allows them to develop and evaluate their explanations to the questions; 3) explanations developed, by students from their evidence to address the questions; 4) evaluation of their explanations, which can include alternative explanations that reflect scientific understanding; and 5) communication and justification of their proposed explanations. These five characteristics entail some hands-on but also minds-on activities for students that form what will be named as *IBSE cycle*.

Among the most important critics to the consideration of IBSE as a privileged teaching and learning strategy is that of relating IBSE good results to the measurement of students' enthusiasm instead of to the actual learning of scientific contents and relation of IBSE with mere procedural and manipulative tasks and learning. In her article Viennot (2010) urges for the need to develop a more conceptual component of IBSE approaches, seeking to guarantee

students' understanding of scientific concepts. For the author, IBSE approaches should be addressed to systematize and organize scientific concepts (more theoretical or more linked to theory) even though these approaches are usually considered as too traditional.

Last aspect we think is essential to be clarified is referred to some epistemological problems that we can find in the IBSE approaches commented until now. We are talking about the fact that, depending on how it is interpreted, inquiry activities can be centered on students' local explanations (the ideas they induce from their experiments and research designs) without any connection with any scientific theory that is seek to teach and to be learnt. Some authors identifying incomplete inquiry practices make reference to practices that are influenced by what is called the *scientific method* (Windschitl et al., 2008) highly widespread among teachers and that gives an unproblematic image of science, oversimplified forms of reasoning and often theory dissociated. According to the authors, a very systematic science that tends to present a unique way of gathering evidences, directly from practical work and without a connection between concepts, laws, principles or scientific models. This approach leads to the superficial explanations mentioned before, that give only answer to a concrete situation but not going beyond. Facing this situation, the research that proposes another way of understanding inquiry having in mind constant connections between phenomena and theory claims for an inquiry that focuses on the construction of models: representations constructed as conventions within a community to support disciplinary activity (Windschitl et al., 2008) or reasoning structures that allow someone to generate predictions and explanations (Schwarz & Gwekwerere, 2007). This particular model-based approach to IBSE is in agreement with the aforementioned views of practical work connected with theory.

## Practical work from the perspective of model-based inquiry

Trying to foster the implementation of inquiry approaches in the science classroom and according to some research results that confirm that practical work can help to the promotion of inquiry (Barrow, 2006), this research proposes a framework for practical work from a model-based inquiry perspective. Based on the traditional IBSE cycle mentioned before, a cycle for practical work could be defined taking into account the potentialities of practical work above mentioned (see Figure 1). Additionally, based on the proposals of a model-based inquiry perspective, we could locate this practical work cycle in two dimension space that include the objects' or observables' world dimension and the ideas' or theoretical world dimension. The ideas world must go beyond students' ideas and make reference to students' constructs that should be in agreement with the scientific theories we want students to learn. The observable world refers to the phenomena observed and the experiments carried out in the science classroom. In a model-based inquiry framework as the one proposed, practical work should be situated in these two worlds, as the context in which to promote scientific reflection and learning, connecting both worlds by a modeling process. Figure 2 tries to represent this proposal.

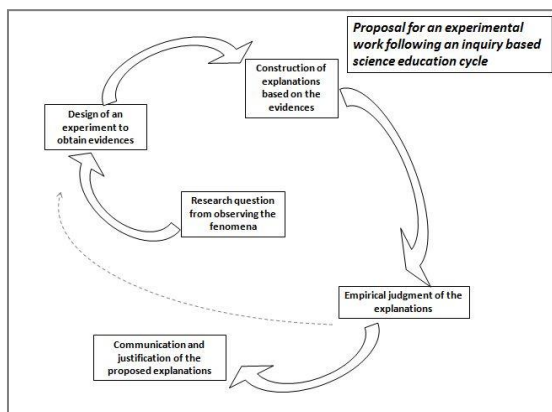


Figure 1. Proposal for a practical work following an IBSE cycle

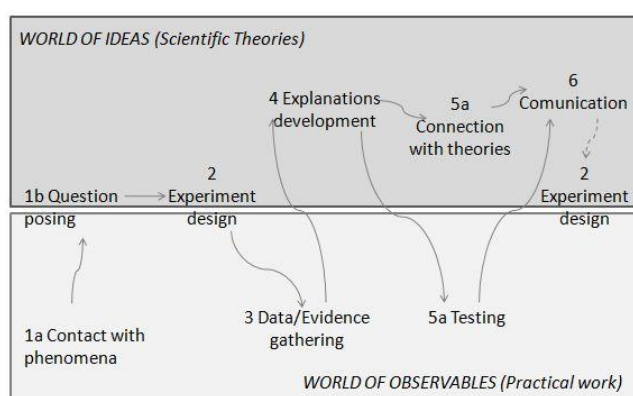


Figure 2. Practical work following an IBSE cycle: connections between the world of ideas and the world of observables

## METHODOLOGY

This research is situated in a qualitative and interpretative research paradigm. Giving the interest of this research on the possible differences and similarities between primary and secondary school teachers, the study addressed the views of four upper primary (M1, M2, M3, M4) and four lower secondary (P1, P2, P3, P4) teachers from both public and semi-private schools.

### Data collection

Trying to connect teachers' views regarding practical work to their own practice, the selected instrument for the data collection was a semi structured interview in which to discuss practical work teaching and learning activities both specially designed for the interview and also coming from the interviewed teachers. The interview was structured in three main blocks that are summarized in Table 1. All interviews were audio-recorded, being this the main source of data. Video data and other sources such as researcher notes and the documents related to the teachers' practical work proposals that guided the interview were used as secondary data.

Block	Description
Block 1 Practical work dimensions	Teachers' views about: main objectives, expected learning, role of practical work in classroom activities, format (including main students tasks), link with theory, teachers' role and evaluation.
Bloc 2 Personal experiences	Narration of own experiences as students regarding science and practical work; view regarding differences between primary and secondary.
Bloc 3 Opinion regarding non inquiry/inquiry activities	Teacher's selection according similarities with their own proposals between two practical work activities given by the researcher (both activities working the same concept, but one more closer to an IBSE approach)

Table1. Interview structure

### Data analysis

Data analysis was carried out in three phases: a first analysis of teachers' views regarding practical work; a second phase in which, starting from the first phase results, some teachers' profiles were defined by considering the existing gap between their views and a model-based inquiry approach of practical work according to the proposed framework; finally, a deeper analysis regarding the factors that could be influencing the proposed profiles.

First analysis was done with Atlas.Ti, labeling those snippets considered more relevant taking into account some aspects coming from the theoretical framework (and already considered when designing the interview) and other ones that were emerging from data while making this first analysis. The considered dimensions were: *Practical work aims*, *Expected students' learning*, *Practical work structure*, *Students' tasks*, *Teacher's role*, *Link between theory and practical work*, *Limitations and facilitators to propose practical work* (in general and with an inquiry approach).

In the second phase and for each of the mentioned dimensions, categories that reflect a closer view to a model-based inquiry approach were identified, together with those reflecting a view not in agreement to this framework. Those requirements considered essential to *facilitate* inquiry, that is, fitting to the inquiry framework defined in this research, were defined for practical work *aims*, expected students' *learning*, students' *tasks* and *link with theory*. Those aspects that were considered to *hinder* inquiry as is understood in this research were also identified when characterizing a more traditional practical work approach or with a non modeling inquiry approach. Finally, some categories were identified that would *difficult inquiry to a higher degree*, being so far from an inquiry approach that the gap for a methodological change would be hard to be achieved. Linking the first and second analysis

results, a deeper understanding of which factors could influence teachers' views was sought in order to be able to assess which mechanism could help teachers' views to evolve towards a model-based inquiry approach.

## RESULTS

First results of the analysis were synthesized in systemic networks in which teachers' answers were classified. By way of example, Figure 3 presents the one of the networks for the dimension "aims of practical work". According to this analysis, we could confirm that main aims considered by teachers were *motivation* in the case of primary school teachers, and *contextualization* of theory, for secondary school teachers.

			M1	M2	M3	M4	P1	P2	P3	P4	
PRACTICAL WORK AIMS  (related to: )	Learning predisposition	To motivate and to increase students' interest	5	x	x	x		x		x	
		To amuse	2	x			x				
	Learning (how to learn)	To learn by doing	2	x	x				x		x
		Classroom methodologies (how to teach)	To facilitate classroom management	2			x		x		
	To detect previous ideas		1	x							
	To contextualize theory		5			x			x	x	x
	To Apply/Check/Prove theory		6	x	x	x			x	x	x
	Content (what to learn)	To complement theory	6	x	x	x			x	x	x
		To connect theory with practical work (modeling)	3			x	x	x			

Figure 3. Analysis of teachers' answers regarding practical work aims

For the rest of the analyzed dimensions, some results could be highlighted. Regarding the expected learning, teachers tend to mention the learning of *science contents*, but other learning targets such as *cognitive abilities* or *nature of science* are less considered. When talking about the *tasks* students should carry out when being engaged in practical work, main references are made to *execution* tasks such as

use of devices but there are few teachers bearing in mind important tasks from an IBSE point of view such as *planning* or *analysis*. Related to an important aspect of the framework defined in this research, the *link between practical work and theory*, most of the interviewed teachers tend to place theory before practical work, in a one way direction link in which once the theory is given, practical work can be started.

For the second phase of the analysis, some criteria were defined for the categories taking into account if they would *hinder* or *facilitate* an inquiry approach such as the one elaborated in this research. This criteria was used to classify teachers into *inquiry profiles (regarding their conception of IBSE)* as we will see further on. Following with the example of the dimension "aims of practical work", Table 2 shows this classification proposal.

Practical work aims		
1	If only aspects related to learning predisposition (to motivate/to amuse) are mentioned	Highly hinders inquiry
2	If only aspects related to how to learn (empiricist view: learning by doing) are mentioned	Highly hinders inquiry
3	If only aspects related to classroom methodologies are mentioned	Highly hinders inquiry
4	If, when talking about content, only contextualization is mentioned	Hinders inquiry
5	If, when talking about content, the link between theory-practical work is considered but only in one way sense (theory → practice or practice → theory)	Hinders inquiry
6	If, when talking about content, the link between theory-practical work is considered in both sense, with the objective of constructing models	Facilitates inquiry

Table 2. Criteria for teachers' inquiry profiles according to their views regarding practical work aims

Once these criteria were defined, also for the rest of dimensions and categories, teachers were classified into *inquiry profiles* considering if their views could hinder or facilitate a model-based inquiry approach for practical work. Taking again "aims of practical work" as an example, teachers were classified as shown in Table 4.

	<i>M1</i>	<i>M2</i>	<i>P3</i>	<i>P4</i>	<i>P2</i>	<i>M3</i>	<i>M4</i>	<i>P1</i>
<b>Practical work aims</b>	<i>Hinders inquiry</i>	<i>Hinders inquiry</i>	<i>Hinders inquiry</i>	<i>Hinders inquiry</i>	<i>Hinders inquiry</i>	<i>Facilitates inquiry</i>	<i>Facilitates inquiry</i>	<i>Facilitates inquiry</i>

Table 4. Analysis of teachers' views regarding practical work aims from the perspective of model based inquiry science education

Applying these criteria and classifying teachers into profiles for the considered dimensions, a global *inquiry profile* was defined for the interviewed teachers' views (see Table 5).

	<i>M1</i>	<i>M2</i>	<i>P2</i>	<i>P4</i>	<i>M3</i>	<i>P3</i>	<i>M4</i>	<i>P1</i>
<b>Global</b>	<i>Highly hinders inquiry</i>	<i>Hinders inquiry</i>	<i>Hinders inquiry</i>	<i>Hinders inquiry</i>	<i>Hinders inquiry</i>	<i>Hinders inquiry</i>	<i>Facilitates inquiry</i>	<i>Facilitates inquiry</i>

Table 5. Teachers' views profiles taking into account to what extent they facilitate a model based inquiry approach for practical work

Being these results quite revealing, with most of teachers (both primary and secondary levels) offering views regarding practical work partially far from an inquiry approach but with

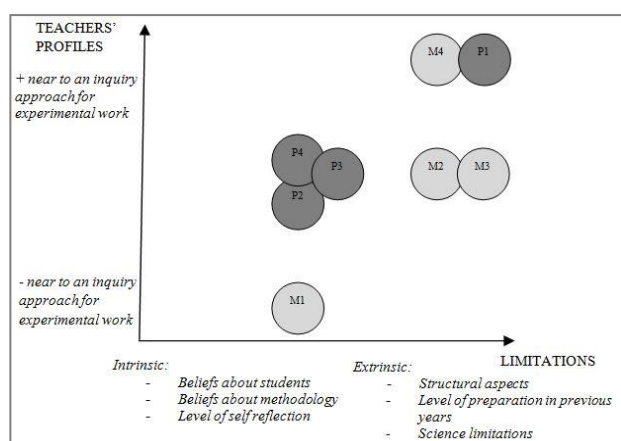


Figure 4. Proposed profile for the classification of teachers' views about inquiry practical work. Correlation with stated limitations.

some potentialities to get closer to this approach, it would be interesting to go further on this analysis trying to identify which could be the mechanisms to make evolve these views by considering the facilitators and limitations mentioned by teachers themselves. To do so, the global profiles defined in the second analysis are correlated with the limitations stated by teachers, classifying these limitations as internal or external considering if they were directly related to teachers, their beliefs and their level of self reflection or if they were more influenced by external factors, such as structural limitations. Figure 4 presents this correlation. As we can see in the graphic, teachers with naive views of inquiry, far from the proposed framework do state both external and internal limitations, although for primary school teachers only external limitations are mentioned. On the other hand, teachers with more sophisticated inquiry views do only state external limitations, which would suggest that for these teachers internal ones have been overcome. Finally, there is only one case in our sample with views further from an inquiry approach, which makes hard for this study to draw any conclusion despite it seems that both external and internal limitations are present.

Trying to overcome these limitations, also an analysis of the possible facilitators should be done. In one hand, for teachers with medium inquiry views, that is those presenting some potentialities to use a model-based inquiry approach in their practical work, we could say that this view was favoured in situations in which they have collaborated with other colleagues or when they have been involved in some specific projects (such as an ICT project). Also when they master the subject they are teaching they feel more confident to carry out different approaches such as an inquiry one. On the other hand, both teachers presenting a profile that virtually fits with the inquiry framework proposed in this research had in common that they have had a regular contact with research and innovative groups, being an important mechanism to be taken into account.

## CONCLUSIONS

This research has made possible to elaborate a framework to characterize a way of proposing practical work that fits within an inquiry based science education (IBSE) approach, specifically that of model-based inquiry. The analysis of the interviewed teachers' views regarding practical work from this framework suggests that, despite the existence of some differences between primary and secondary school teachers' views, there is not too much to

highlight regarding these differences. Practical work has still an important role for teachers in science education, but the proposed approaches are quite traditional which would suggest that a renovation of this practical work inspired in the proposed inquiry framework could be beneficial at two levels: first, to take advantage of practical work potentialities, widely highlighted by research in science education; and second, as a first step to bring inquiry approaches closer to the science classroom by introducing this perspective to guide something that it is already done. In this sense, the fact that the majority of the interviewed teachers present views with some potentialities for an inquiry practical work, would suggest the feasibility of this approach.

Regarding the methodology proposed for this research, the fact that the interview has been developed around teachers' own practical work designs has made possible to analyze their views from an approach closer to their real teaching practice. On the other hand, to give to teachers the opportunity to see a traditional practical work activity transformed into an inquiry approach (block 3 of the interview) has allowed teachers to contrast their own teaching practice with both alternatives, helping to emerge the limitations and facilitators that could condition their day by day selection between one and the other approach. Finally, we think that the proposed dimensions and categories for the analysis of teachers' views can be used as a basis for future large scale studies.

## NOTES

<sup>1</sup> The inquiry framework developed in this research has been carried out in the context of discussing the nature of scientific competence in the I+D project COMPEC "Análisis de dificultades, propuestas de formación y elaboración de materiales didácticos como "buenas prácticas" en el ámbito", ref. EDU2009:08885, Ministerio de Ciencia e Innovación Transformative

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## **DESCRIPTION OF PRACTICE TEACHING FROM THE SYSTEMATIC OBSERVATION OF THE WORKING CLASS IN HIGH SCHOOL**

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*Abstract:* Addresses the practice of teachers of science, research phenomenon through a detailed analysis of previous classroom sessions video-recorded, three in average teacher, "from an" Analytical Model of Teaching Practice, from Systematic Observation ', in which each session is divided into 5 minute clips to be analyzed, having a total of up to 10 clips per class session, to record the frequency of video-recorded events which identifies the presence or absence of actions of each of the five categories of analysis of teaching practice, previously established role of student, teacher role, learning object, the object of evaluation and assessment concerning ", which allows statistical manipulation data.

The characterization of work in the classroom of high school science teachers, we can provide information regarding the key elements that constitute the practice of teachers. Preliminary results show academic activities typical of a traditional practice, characterized by the absence of experimental activities, making it necessary to rethink the training and retraining of teachers in the exercise of basic education in Mexico.

*Keywords:* teaching practice, systematic observation, science teacher education, working class

### **INTRODUCTION**

#### **-The Problem**

Previous research work on teacher's initial and in-service training (Rodríguez & López-Mota, 2006) reports that despite teachers taking many in-service courses, there are few signs of significant changes in teaching as well as in learning science. This leads us to think that there is a problem with the nature of work developed within the classrooms that is not easily changed by either initial training or in-service courses. So it seems interesting to know why it is so hard to change it, by understanding what it is the kind of teaching practice displayed within the classrooms.

Recent studies about the teaching practice, based on video recorded sessions, have given solid empirical basis to develop quality teaching (Roth et al., 2001; Duit et al., 2005). Nevertheless, several researchers (Lederman, Wade & Bell, 1998; Tsai, 2002) express their concern for having at not hand much more needed results on what happens within the classrooms at schools.

With this research we wanted to characterize what happens within classrooms -as a direct phenomenon of study- by analyzing detailed previously recorded sessions -three on average for every teacher- taking on board an analytical model of teaching practice, based on systematic observation.

#### **-Framework**



The teaching practice has been studied under several perspectives: practical implications from theoretical perspectives (Pozo & Gomez, 1998; ethnographical approaches (Candela, 1999) and description of the phenomenon (Duit et al., 2005; López-Mota, Rodríguez, Flores, Martínez & Antonio, 2007; Rodríguez, 2007; Flores, 2009).

The first perspective towards teaching practice is derived from theoretical stands of learning traditional, discovery, significant and constructivistic- but does not offer empirical evidence to justify such categories. The second one comes from an ethnographical point of view and describes cases of what happens within classrooms, but having problems in developing large scale studies because of its methodology. The third one -in which is based the present study- offers an advantage: the systematic description of teaching practice (Flores, 2009) who has defined analytical categories and empirical indicators of pedagogical actions of teachers within the classrooms.

## **RATIONALE**

This type of investigation might bring new light to establish educational policies, based on extended empirical data and bring about changes in the nature of the teaching practice in the classrooms. We think it is eventually possible to develop a theory of teaching practice if we base our descriptions of what happens in the classroom, in an analytical model that is as well based on systematic observations. This means, with the aid of cognitive theories of learning and analytical categories coming from observation: a strategic blend of *a priori* and *a posteriori* procedures.

## **METHODS**

To characterize the educational practice of natural science teachers, through its detailed analysis of video-recorded class previously, we initially set out to build a '*Analytical Model of the Teaching Practice from the Systematic Observation*' (MAPADOS) -by its Spanish acronym- (López-Mota, López, Rodríguez & Flores, 2010), which is constituted two categorical systems whose behavioral taxonomies are the product of previous work (López-Mota et al., 2007; Flores & López-Mota, 2009) and from the conceptual level. The first categorical system, which is used in this work, consists of five analytical categories: *student role, teacher's roll, object of learning, evaluation object and references for evaluation*. This taxonomy has the virtue of indicators, from 4 to 10 for each category, originate from an empirical analysis of classroom observation (Flores, 2009), giving a total of 29 shares for the 5 categories with which analyze teaching practice, which allows a wide range of actions taken by the teacher in the classroom work. By splitting the sessions in clips of 5 minutes you get a large number of events to analyze, the model proposes to sweep the observation of more than 50% of each class session, recording only what happens on the odd or even for clips each class session, but always recording what happens in the first and last clip of the class. The model implies that each videotape, for a class session, which in theory is 50 minutes, split into 5 minute clips to be analyzed, having a total of up to 10 clips per session of class to record the frequency of video-recorded events in which it identifies the presence or absence of actions of each of the five categories of analysis of teaching practice previously established statistical manipulation of data.

### **-Procedure**

To make it possible to obtain the reliability of the observations, it was necessary that pairs of observations were made of each category in the same teacher. To then get the percentage of agreement, the margin should be at least 80%. We apply the methodology 1 of MAPADOS at a sample of 17 science teachers, biology, physics and chemistry in secondary schools from morning and afternoon in Mexico City.



## RESULTS

The 17 teachers were observed in a total of 45 class sessions for an average of 2.64 sessions per teacher, as class time in schools is 50 minutes, total time, in theory, intended for these kinds of science was 37 hours. But when doing field work, we find that the reality was that the 45 class sessions lasted 28 hours and 9 minutes, which is losing roughly 25% of the time devoted to work with students.

Which does not lead to identifying a first point on which we must work in order to ensure the quality of education, especially when the faculty have spoken out against the curricular reforms by lower -apparent- content in the plans study.

By dividing the class sessions in clips of 5 minutes was possible to obtain a total of 331 events to be analyzed using 29 indicators, but because the model does not propose to analyze 100% of the session, but a scan class representative in this case 210 clips were found which means were analyzed 17 hours and 51 minutes, which gives a percentage of scanning for the analysis of the kinds of 63.41%, which is a fairly representative value of teaching practice. Concerning the characterization of teaching practice, Table No. 1 shows the results of the 17 teachers under the teachers' actions more frequently in the classroom. Table No. 2 shows the results of the 17 teachers under the teachers' actions less frequently in the classroom.

Regarding the most common registered shares in the class of teachers, it is noteworthy that occupies the first place-for the total sample, make reference to the behavior of the students: "Students keep composure before the intervention or activity performed by the teacher". And the other four refer to an expository teaching practice in which students act and interact primarily at the express request of the teacher. In contrast, the least favorable action in the classroom is referred to the students participate on their own initiative. The other four actions that are least in teaching are in the same vein, it does not refer to the possibility of interpretation of science or phenomena by students and the lack of real interaction between them and the teacher beyond listening.

Table No. 1: Stocks with greater frequency

Category	Action	Frequency	Subjects
Student role	I-6: Students keep composure before the intervention or activity conducted by the teacher	162	17
Object of Learning	III-1: The teacher displays or presents the content or phenomena using definitions and / or contextualized and / or instantiations, without room for interpretation by the students.	111	17
Teacher's rol	II-1: The teacher verbally, with or without teaching aids, described or set forth concepts and ideas of school knowledge	98	17
Student role	I-2: The student writes a specific request or at the direction of the teacher.	97	16
Student role	I-6: The student teachers expressed or spontaneously request a verbal response, written or graphic, or a direct challenge to the group in general.	93	16

Table No. 2: Stocks with less frequency

Category	Action	Frequency	Subjects
Student role	I-7: The student takes the initiative itself part of the exhibition of the teacher and express in their own words, to broaden the understanding of the learning object	1	1
Object of Learning	III-4: Teaching materials and resources used to define and / or contextualize and / or exemplify, with room for interpretation by the students.	7	2
References for evaluation	V-3: The teacher points out the differences in performances that have a student for himself.	8	4
Object of Learning	III-2: The teacher displays or presents the content or phenomena giving room for interpretation by the students.	10	3
Teacher's rol	II-6: Happens to teams during the implementation of a pilot, or not being able to interact with students	15	6

## CONCLUSIONS AND IMPLICATIONS

We can say in conclusion that it is possible to account for the practice of teaching as a phenomenon of study, from the detailed description of it by categories of analysis that are reflected in the actions taken or not teachers at its class. As the core elements to characterize the work in the classroom of high school science teachers, we find that your practice focuses on the exposure of content through definitions and/or contextualize that leave no room for interpretation by the students, lack of laboratory practice into context the phenomenon to study and teaching practices that enable centralized interaction among students about scientific knowledge and assessment activities focused on compliance or otherwise of the activities tasks and / or product class and not in the analysis of individual performances of each student.

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# IN-SERVICE BIOLOGY TEACHERS' PCK DEVELOPMENT: ANTITHETIC ROLES OF SELF EFFICACY

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**Abstract:** The focus of this study was the development of pedagogical content knowledge (PCK) of two teachers during a professional development course in biology. Pre and post interviews as well as recordings during the course made it possible to track whether PCK was developed or not. Self efficacy was the central PCK component, enabling development in Bert's case and hindering it in Anna's case. This study demonstrates the importance of this PCK component and the importance of the connections between the components for integrated PCK development.

**Keywords:** biology, professional development, pedagogical content knowledge, PCK development, self efficacy

## INTRODUCTION

The context of this paper is the development of a professional development (PD) course (Scheuch, Keller, Radits, & Pass, 2010) in biology to improve teaching of field ecology. The overall aim of the course is the development of in-service biology teachers' pedagogical content knowledge (PCK); the teachers choose the emphasis for their learning individually. In this study, which addressed the development of PCK of teachers through participation in this PD course, the PCK component self efficacy emerged as a central component enabling and disabling development.

## THEORETICAL BACKGROUND

### Professional Development

Reviews by Lipowsky (2010) from a pedagogical view and by Hewson (2007) specifically in science education research, have revealed the following factors for effective PD courses: 1) The duration of the course is important – the longer the course lasts, the more development can take place and the more of the content of the course is transferred to the participants' classes. 2) Exchange between the teachers and sharing work on their teaching are needed to further develop their understanding about what they are doing in class. 3) Teaching practice should be included, so the PD course should challenge the classroom practice within its programme as well. 4) The teachers' experience based on former practice and the practice conducted within the courses should be reflected. 5) PCK as professional knowledge domain should be addressed explicitly in the course by the teacher educators as well as the teachers. In studies which focus on the development of PCK in PD courses, the factors of effective PD have also been found (e.g. J. H. Van Driel, Verloop, & Vos, 1998: changing craft knowledge of teachers needs reflected teaching practice and the focus on the learning of the students).

### Pedagogical Content Knowledge

Pedagogical content knowledge (PCK) is a domain of teacher knowledge (beside pedagogical knowledge and content knowledge), which is important for the teaching of a specific subject and even a specific topic (Shulman, 1986; 1987). PCK research is a very wide area, with lots of different conceptions and attributions of PCK. One tension has to be mentioned: Although it is described as the "*special form of professional knowledge*" (Shulman, 1987, p.8), it is individually developed and far from being a collective body of knowledge. Cochran et al. reacted with a constructivist conception in replacing PCK by PCKg (that means pedagogical

content knowing and also includes more tacit forms of knowledge) or more recent Wieringa (2011) in her re-reading of Schön's "The Reflective Practitioner" (1983) where she sees PCK as some kind of practical knowledge – opposing formal knowledge. These different characteristics are a result of the individual development of PCK, as it is developed by the teachers during practice of teaching and the reflection upon the practice (Park & Oliver, 2008; J.H. Van Driel, Jong, & Verloop, 2002); therefore it results in an individual or idiosyncratic knowledge (Park & Oliver, 2008; J. H. Van Driel & Berry, 2010). Abell (2008) asks for an overarching model of PCK development, because actually the developmental routes of the teachers are very isolated (Abell, Rogers, Hanuscin, Lee, & Gagnon, 2008). Park & Oliver (2008) developed one model based on Magnusson, Krajcik et al. (1999), where the growth of the teachers' PCK is central. Reflection in Action as well as Reflection on Action turned up to be crucial (Park & Oliver, 2008). In a most recent review about studies documenting PCK development, Schneider & Plasman (2011) have found general developmental pathways during teaching biographies for the several components within the PCK conception of Magnusson et al. (1999). So there have been and still are attempts in getting the development conceptualised; in this paper we take the model of Park & Oliver (2008) because this matches our intentions best. The six components are: Orientations to Teaching Science (OTS); Knowledge of Students' Understanding in Science (KSUS); Knowledge of Science Curriculum (KSC); Knowledge of Instructional Strategies and Representations for Teaching Science (KISR); Knowledge of Assessment of Science Learning (KA); Teacher Efficacy (TE). Teacher efficacy was newly introduced into the model by Park & Oliver (2008) and labelled as "*an affective affiliate of PCK*" (p 270). They described that it "*was a highly subject specific version of teacher efficacy in that it was related to teacher beliefs about their ability to enact effective teaching methods for specific teaching goals*" (p 270).

## RESEARCH QUESTION

Our research question addresses the development of teachers' PCK in ecology: How does the teacher's PCK develop by participating in our in-service PD course? In this paper we focus on the role of self efficacy in the development of PCK.

## METHODS & PARTICIPANTS

The pre-post interview study follows a pragmatic research approach because the results should help to improve further courses. The first interviews were conducted before the course started and the post interviews were held one to two years after the course. The interviews were semi-structured, guided interviews with longer narratives about biology classes in the topic ecology and outdoor biology. Hashweh (2005) made clear that planning instruction as well as reflecting lessons elicits teachers' PCK, therefore those narrative sections about their lessons were important. Previous studies (Keller & Scheuch, 2010a, 2010b; Scheuch & Heidinger, 2009) were conducted to develop the research rationale and the interview guideline. Additionally included were questions of the teacher beliefs interview (Luft & Roehrig, 2007), to make the teachers reason about teaching ecological topics. The teachers were asked to present a teaching sequence they were proud of; the interviewer used questions to highlight every aspect and to get an overall impression of this/these sequence/s.

In total, 23 teachers participated in the course from primary school to upper secondary school. The four volunteers participating in the study were experienced teachers and studied at University of Vienna for lower and upper Secondary Schools called Gymnasium.

Teacher (synonym)	Subjects	Teaching practice (yrs)	Age
Fiona	Biology, Sports	9 (recently came back after maternity leave)	47
Clara	Biology, Zoology	6 (worked as biologist before)	45
<b>Bert</b>	<b>Biology, French</b>	<b>12</b>	<b>38</b>
<b>Anna</b>	<b>Biology, Religious Education</b>	<b>26</b>	<b>54</b>

For this paper we focus on **Anna** and **Bert**, because in their cases self efficacy turned out to be the most important PCK component.

### **Data Analysis**

The data - from interviews as well as from recordings collected during the course - were transcribed verbatim; the latter were working sessions in the afternoon, plenary discussions in the evening, a discussion about reflecting a lesson with the model of PCK itself, course feedback by all participants. The transcripts were coded with deductive PCK categories derived from Park & Oliver (2008). The methodological approach was the qualitative content analysis by Mayring (2010). Each teacher was partly coded by a second person as well – the coding and understanding of the interpretation were discussed until common sense was reached and the blurriness of the applied categories was clarified. Based on this analysis a case study for each teacher was elaborated, reconstructing the teachers' reasoning out of the reported results of the PCK interviews. Those reconstructions include descriptions of the teaching by the teachers including their orientations, aims as well as routines. These reconstructions can be looked at as being the subjective theories of the teachers. In the results of the PCK development only explicit PCK development was considered, which means that the teacher had to make his/her growth explicit and/or the process data helped to identify the progress. Data triangulation with transcripts of process data was conducted for validation of the reported PCK development by the researchers. All other developments, which could also happen easily during almost three years of teaching, were excluded.

### **RESULTS**

In this section the two cases are presented. The results are structured as follows: First their overall subjective theory of teaching their topic; Second the component of self efficacy and connections to other PCK components; Third the PCK development we detected.

#### **Bert**

Subjective theory of Bert: The content, in this case ecology, is very important for him. He is fond of good lesson preparation, and further refinement of his lesson plans reflecting the experience is important as well; so he continuously improves his biology classes. He is aware of his students' interests and tries to include them in his biology class, e.g. he encourages his students to bring interesting phenomena to his class. He works with complex assignments to elicit the understanding of his students – not only to get the grades, but to get feedback about the students' understanding as well. Another focus is the preparation of the students for future written exams in biology at upper secondary levels.

Results from the pre interview: The category of self efficacy occurred in two ways. First, when he looked back at his biography as a novice teacher. In earlier years he easily drew back when there were difficulties by his students in understanding a topic and developed resistance to the teacher and the topic. He avoided the resistance and did not engage in the students' learning. Later he developed strategies to cope with this problem. The component SE is connected with the KSUS, resulting in a different teaching strategy (KISR) with a curricular argument (KSC). A quotation to illustrate the analysis: “...for example osmosis. Earlier in my career I taught it and finished it, knowing that not everybody had understood. I didn't want to talk for another three lessons, because I had already told them everything. Now I am converted, I give them more examples; my students make experiments on that topic. That needs more time, but now I know that I can build on that knowledge later on. For example in the context of teaching excretion....” (pre-§62). Asking for his expectations for the PD course he stated: “...It is most delicate for a biology teacher to go outdoors; you can easily look like a fool. [...] I think that it helps to develop more routine and know more methodological approaches, [...], these aspects were neglected in my pre-service education.” (pre-§138). So he wanted to get more SE during the PD course for his future outdoor teaching through learning new strategies and methods (KISR).

Bert planned and conducted a teaching sequence with fieldwork in the first grade of lower secondary level (kids aged 10-11 years) during the PD course. The topics were “seeds and fruits”. The class consisted of high achievers who were expected to complete the lower secondary level in three instead of four years.

Results from the post interview: Bert was more confident in dealing with less favoured topics like plant families, his self efficacy had developed along with a teaching strategy. He gave the students more time to elaborate on a topic: *“With animals it would be easier, but with plants [...]. For years I had had the material about common plant families in my drawer and this year I tried to use it. Asteracea, Lamiacea and so on..., and this topic was not received enthusiastically. I had to face resistance for a few lessons, but after some time, when they knew a bit more about it, they liked it. Because then they could identify the most common plant families, they had a feeling of success. My strategy was to start in small portions – each beginning of the lesson one family was presented, for the rest of the lesson we did another topic; for each plant family two of the students prepared a presentation and a poster – the posters stayed in the classroom. Thus they learned it in small doses.”* (post-§72 & 76). Within his fruits project he also connected several PCK components more closely in taking more responsibility for the learning and the interests of the students, with the curriculum in mind and with his confidence that he can build on their special abilities and interests: *“During the project I included other topics as well, which would have come later this year, but the students asked questions about them. For example, photosynthesis and plant morphology to get to the point that they could explain ‘Where does the sugar in the rose hip come from?’. Another example is chemical testing for the substances fat, sugar and starch in seeds. This would not be possible with other kids, but with the high achievers I could try it.”* (post-§102). PCK-development of Bert: His self efficacy was developed and moved into his focus and was also more closely connected with two other components after the PD course: KSUS & KSC! This development was already implicit in the pre-interview, but during the course Bert got to know the PCK model by Park & Oliver (2008), presented by the teacher educators as a grid for reflection on the project: *“As a novice teacher I was tortured to formulate the aims for a lesson - and what happens? You take the whole content and write it down e.g. ‘text book p 27-29’. With this [PCK] grid it is not enough to state ‘the student has to know what a stone fruit is’, but the aim is something higher-ranking and this is reflected in the six [PCK-] components. You become more conscious about why you teach this topic and in what sequence...”* (PCK discussion-§31). At the end of the post interview he explicitly said that SE is a PCK component which helps him teach biology: *“...some topics are important to me and the curriculum and so I insist on teaching them, I explain to my students’ why I do so and help them to work on them...”* (post-§150).

## Anna

Subjective theory of Anna: A good relationship with the students is most important for her, biology content is important as well. Her lesson preparation happens last minute; in her biology class the topic is elaborated in a teacher-student-conversation, where questions and interests of her students are very important. She gives assignments only to grade her students. She likes being a biology teacher very much but she is not satisfied with her preparation style and the stress resulting from her curriculum delay at the end of the school year.

Results from the pre-interview: In the following quotation all the points of Anna’s characterization aggregate: *“At the end of the school year I have to rush through the topics that are necessary for completing the state curriculum. When I tell my students, that I will have to advance fast, they frequently ask me, ‘Are you really sure that you will make it?’.”* (pre-§52). Self efficacy (SE) is represented in the intense relationship with her students; this is the basis for her teaching and is connected with her perception of her students; her guiding aim is: Students should not lose interest in biology; immediate learning of one topic is less

important for her. Therefore assessment is only done with the purpose of grading: *“Effective testing is done by me only when I have to do it.”* (pre-§46). Her answer to the question about a teaching sequence she is really satisfied with was the following: *“It upsets me that I cannot recall any situations that I’m 100% proud of. All I remember is a sequence about spiders in the context of a PD seminar, where I had to work on all aspects during planning, because I had to teach biology in English.”* (pre-§12). She mentions that this was nearly a perfect sequence because she was forced to plan ahead, also because the colleagues of the PD course and her headmaster would attend the lesson. In describing the learning of the students in this example she goes into great detail, connecting several PCK components like KSUS, KISR as well as SE. Moreover, assessment (KA) also turned up in an informal way: *„I had enough time to work with a comic I had prepared as an additional activity. The students were asked to identify mistakes and they did not only find the most obvious things, but also details e.g. that the spider was drawn like an insect with three major body parts instead of two. They looked very accurately and I was really satisfied with these results.”* (pre-§12). During the PD course she was not able to conduct a project. She just developed material for observing the behaviour of mallard ducks with the focus on behavioural ecology in the tradition of Lorenz (1978). But even this material was only developed because she promised a colleague in the course to do so: *“We built a group [in the PD course] and wanted to develop something in behavioural ecology. We did so by sharing work; therefore I had the moral pressure to deliver the working sheets. Otherwise I would not have made it.”* (post-§18).

Results from the post interview: She was not satisfied with a joint curriculum project with chemistry and physics on water quality of a creek in the pre interview and this was still the case in the post interview. She complained about the routine which made this course boring for her and her colleagues: *“You cannot avoid losing your enthusiasm if you present a topic again and again. And this is transferred to your students.”* (post-§106). During the PD course we offered a fictitious story about a small hydropower plant to embed our field work at the creek and she claimed that this was a good idea. Once again she stated that she wanted to include this idea, but in the meantime she missed two chances to improve her water curriculum: *“...I want to implement this idea which we had in the PD course. I really liked it, when you embedded the analysis of the creek in this story about the potential for a hydro power plant. We should introduce such ideas; ...”* (post-§100). The PCK component SE was displayed identically in the post interview, all aspects could be reproduced. This is also the case in other aspects, for example, her stress with the lesson preparation: *“... It happens to me in my preparation, that – even when I start planning early – writing down the material is done only last minute.”* (post-§50).

PCK development of Anna: In both interviews the SE was very important and her prominent PCK component; It includes the good relationship with her students; the other components are first of all linked to SE. She makes the importance of this component explicit: *“... Efficacy is the most important point for me - what is my mission? Then, the rest of the [PCK] components nearly filled in by themselves and afterwards the connections [between the categories] can also be seen. This is very helpful for planning and reflecting my lesson.”* (PCK discussion-§2). This quotation from the PD course reflects her discovery of this component in working with PCK within the PD course. From this category onward she started planning her lesson and was overwhelmed by the result. But in the post interview it turned out that she had not transferred this strategy to her everyday work. She still reports about being dissatisfied with her preparation. Therefore no PCK development could be detected.

## DISCUSSION & OUTLOOK

One teacher did develop PCK, the other one did not. Self efficacy played an important role for the development of PCK in these two cases even if it is an antithetic role. Bert, who developed both PCK and stronger connections between the components, planned and



conducted a project with self efficacy as an important PCK category for himself in mind. In his case, self efficacy was the trigger to develop the PCK. Bert had already been aware of the changes over the years, reported his self efficacy in the pre interview, and mentioned it explicitly in the post interview, after introducing the PCK concept. This is expressed in the development and the fact that he does no longer suffer from the stress of completing the class curriculum within a year but can work on important concepts, knowing that he can build on them later on (connection between SE, KSUS & KSC). This strong connection was detected only in the post interview and was argued by him in several examples. He took the responsibility for helping the students to learn a topic. This aspect is in line with several authors: The consideration of the KSUS is a clue for developing PCK (e.g. Hashweh, 2005; Van Driel & Berry, 2010; Van Driel, Verloop, & Vos, 1998). Anna, on the other hand, did not conduct a project; therefore no practice with the given topic took place. This also restricted her reflection to the development without the teaching experience. In her case the self efficacy is a central component as well, but it seemed to hinder any development because in relying on her relationship and constructing her instruction around this factor, she had not felt the need to follow new paths. She has an elaborate content knowledge at hand, and therefore does not need a precise lesson plan but can start with a topic right away. As long as this relationship to her students and to the topic is not disturbed (e.g. by curriculum demands or assessment needs) she is very satisfied, also in reaching her personal goal (not loosing interest and some students should decide for a science or medical career) and in meeting the interests of her students. No development could be detected, although she was given matching offers to her self-reported problems.

Therefore we could prove the claim of Park & Oliver (2008) that SE is a central new component of the hexagon model of PCK. But teacher educators have to be aware of the complex interaction between the PCK components and their very different influences on each other. In comparing these two cases, reflected practice was the difference, and therefore provides a hint why Bert developed PCK and Anna did not. Further research on the role of the single PCK components in dependence on each other has to be done – to further develop the PCK model as such as well as to understand the potential for developing PCK in teacher education. One idea about the role of self efficacy is that SE is the antipode of the component teacher's orientation to teaching the subject (OTS). While OTS represents the teacher's beliefs to the school subject and the discipline itself; self efficacy is a kind of moderator component how the teaching is realized. Further research on this question has to be done.

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# DEVELOPING NETWORKS TO SUPPORT SCIENCE TEACHERS WORK

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## INTRODUCTION

In educational research literature the concept of network has emerged as a strategy to support teachers' professional development (Huberman, 1995; Jackson & Temperley, 2007; Van Driel, Beijaard, & Verloop, 2001). This paper reports on a study about teachers' collaboration in networks on improving the quality of their own teaching practices. These networks exist at the meso-level of the educational system between the micro-realities of teachers' individual practice and the macro-level, where educational policies and intentions in the educational system are formulated. At this level networks provide an organizational frame where individual teachers' private knowledge and the public knowledge in the educational system can mix with the intention of improving teachers practices (Lieberman, 2000). The research question that guided this study is: How can networks provide opportunities for teachers from different schools to collaborate on improving the quality of their own teaching practice?

The context in which these networks were studied was a development project that was co-funded by the Danish Ministry of Education and four municipalities. The aims were to develop collaborative activities in primary science teacher communities in schools and in networks between teachers from different schools in each municipality. Each network were organized and moderated by a municipal science coordinator.

## ANALYTICAL FRAMEWORK

The concept of *Network Learning Communities* (Jackson & Temperley, 2007; Lieberman, 2000; Stoll, Bolam, McMahon, Wallace, & Thomas, 2006) was used to analyze possibilities and constraints of network activities that aimed to improve participating teachers' individual practice. A characteristic feature of successful and sustainable networks is that the knowledge base balance between the private knowledge of the teachers and the public knowledge that informs the teachers practice through collaborative activities in the network (Busch & Sølberg, 2004; Jackson & Temperley, 2007; Lieberman, 2000; Lieberman & Wood, 2002).

## RATIONALE

A statistical study aimed at, amongst other, estimating the effect of network communities on pupils outcome support the hypothesis that pupils do better in schools where teachers collaborate in networks (Jackson & Temperley, 2007). Similar findings is documented in the German SINUS-project, where pupils from schools participating in the SINUS-programme scored higher in PISA 2003 compared with pupils from schools not participating. A characteristic feature of the activities in SINUS is that communities of teachers from different schools collaborate in clusters about collective activities that aim at improving teacher collaboration, teachers' individual practice and sharing best practice (Ostermeier, Prenzel, & Duit, 2010)

Standard professional development programs are problematic, because they deliver “one size fits all”-activities that are not easily adaptable to teachers own practice. On the other hand, networks provide the organizational framework that is highly user driven around the interests and needs of the participants (Lieberman, 2000); (Lieberman & McLaughlin, 1992). In their review on strategies to reform science education Van Driel et al (2001) claim that *learning in network* is a powerful strategy to achieve lasting change in teachers’ professional knowledge. Two arguments support this claim. First, experienced teachers’ natural resistance to innovation and change can be reduced by learning in networks. Second, learning in network may be particularly effective, when teachers share similar tasks, but have different experiences performing these tasks in their own school. Coming together to share knowledge provide opportunities for teachers’ to review different practices and develop a shared attitude about best practice.

## METHOD

In the present study municipal science coordinators were asked to write narratives about network development in their municipality. This provided the researchers with four different accounts on network development. Their written narratives were then condensed into descriptions of the development of networks at the municipal level that provided information about possibilities and constraints for developing networks. The narratives outlined both activities, interactions between different stakeholders (municipal science coordinators, teachers, other resource persons and the municipality) and the overall progress during the three year time span of the development project. Then the researcher supplemented the narratives with interpretations about what elements that facilitated or constrained the development of networks. To increase validity the narratives with the researchers’ interpretation were the read by the municipal science coordinators and the revised and edited according to their suggestions. The narratives provided rich information about diverse conditions for developing networks. Diversity of the narratives was seen as a quality because of the explorative nature of the study.

In the next step the narratives were analyzed for patterns in elements that facilitated or constrained the development of networks. The first author then asked the municipal science coordinators to co-interpretate the patterns that had emerged in the narratives. Thus the municipal science coordinators contributed to a deeper understanding of elements that facilitated or constrained the network development (Kvale, 2004).

The written narratives were triangulated with two additional sources of information. The participating teachers’ response to a longitudinal survey and the assessment report that each school submitted when the development project ended. These data sources provided information from the teachers’ perspective about their attitude towards teacher-to-teacher collaboration within their own school, in network activities between schools and the municipal support in the networks. The longitudinal survey consisted of a questionnaire that was distributed at the beginning and end of the development project. It contained both closed and open-ended questions. Teachers’ responses to closed questions were subject to a statistical analysis. Differences between their initial and final responses were tested for significant variations by using t-test. The responses to open-ended questions were categorized according to whether the teachers expressed a positive, neutral or negative attitude about teacher-to-teacher collaboration, network activities and municipal support. The assessment reports that each school submitted at the end of the project were collective accounts from the group of teachers participating in the project. The assessment was guided by open-ended questions and the responses were categorized similarly to the individual teachers’ responses to the open-ended questions in the longitudinal

survey. For details about these two sources of information see the technical report (Sillasen & Valero, 2011).

## RESULTS

The study revealed several elements that facilitated a sustainable development of teachers' collaboration in networks.

One element was the recruitment of an experienced science teacher to guide teachers in their collaborative activities both within the schools and in network activities. For some network groups the guidance of an experienced science teacher was of great value to inspire the teachers on developing new activities.

A second element of the network was the biannual workshops where teachers from different schools came together to engage in collective activities. In one municipality the science coordinator had chosen outdoor education as a common theme for development of teaching activities. In the municipal workshop an external resource person supported the teachers in their collective effort to develop teaching activities using the framework of outdoor education.

A third element of the network was the creation of network groups of particular interest. One example is from a municipality in a rural district with many small schools. In one of the municipal workshops teachers from these small schools met and formed the "rural schools network". In the assessment report from one of these rural schools teachers wrote that *"the rural schools network" was a very fruitful community, because all teachers in the network shared similar conditions and challenges in teaching science.*

A fourth element was the participation of the municipal science coordinators in network formation. The municipal science consultant's participation in network activities was multifunctional. S/he communicated with schools about what their needs are for external support, planned collective activities, invited external actors, organized workshops, applied for funding for network activities, found examples of good practice within the network that could be shared and coordinated local support for schools and network activities. An important personal competence of these municipal science coordinators was to be highly adaptable to the needs and demands of the participating teachers in the network. Their participation at various levels of the network activities was highly valued by the participating teachers.

The study also provided examples of network activities that constrained sustainability of the network. One important element was that the collaborative activities must relate directly to teachers daily practice. Otherwise there was a risk that teachers did not feel obliged to engage in future network activities. A second element was that the network needs a dedicated moderator to coordinate, communicate and recruit teachers to engage in network activities. A third element was that the moderator needs support from the municipality or a local science centre to sustain the network. Otherwise the moderator might feel declined to continue network moderation if the network was not institutionalized.

## CONCLUSIONS

The research presented here shows that developing networks provide opportunities for teachers to come together to share knowledge about their individual teaching, to be inspired by external resource persons and to commit to developing new teaching activities in collaboration with teachers from other schools. But the sustainability of these network activities depended strongly on whether the teachers considered the outcome to be useful in their own teaching practice. Second, developing

networks is a fragile process that requires commitment from various levels of the educational system (teachers, municipal science coordinators, school leaders and science centers).

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# IN-SERVICE SCIENCE TEACHERS' TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE CONFIDENCE LEVELS AND VIEWS ABOUT TECHNOLOGY-RICH ENVIRONMENTS

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*Abstract:* Science teachers need to be able to integrate technology into science teaching. Identifying science teachers' confidence levels in technological pedagogical content knowledge (TPCK) and determining their views about using TRE in science instruction is an important issue since it can reveal if and how they will use TREs. Therefore, this study aims to address challenges faced by in-service science teachers during creating TREs. The data were gathered through the TPCK confidence survey and subsequent interviews. Ninety-five in-service science teachers from public middle schools in Ankara participated in this study. Additionally, interviews were conducted with four voluntary participants. Findings showed that in-service science teachers had a low level of confidence in using technology in science teaching and they stressed that they need professional development for using TRE for effective and meaningful science teaching.

*Keywords:* Technological Pedagogical Content Knowledge, Teacher Confidence, In-Service Teachers, Technology-Rich Environments

## INTRODUCTION

The turn of the 21<sup>st</sup> century marked the beginning of a much common and widespread use of computer technologies in science classrooms and practically everywhere else because personal computer hardware with even higher capacities became affordable to larger populations and applications with enhanced visual characteristics were created with lesser effort not only by computer experts but also by science educators. Although not sufficient for all teachers, several initiatives and efforts emerged in order to help science teachers to better understand associated teaching methodologies and benefits of Technology-Rich Environments (TRE) in science.

Knowledge of the natural sciences is connected to explain objects, phenomena, and their interactions in the natural world (Lunetta, Hofstein, & Clough, 2007). Therefore, learning about nature should take place through interaction (careful observation, manipulation, and drawing conclusions) with the phenomena and not in an abstract way. The constructivist approach to teaching and learning stresses that learners are not blank slates on which to write freely. Rather they come to the learning environments with all sorts of pre-conceptions and these are often times are not scientifically acceptable. Science teachers as facilitators of learning in classrooms design meaningful learning activities and environments in which students can gradually construct an understanding compatible with the scientifically acceptable ones.

Hence, science instruction should help them “(a) add powerful, durable, and generative examples to their repertoire of ideas; and (b) enable students to grapple with their full repertoire of ideas to form a more coherent perspective on the scientific domain. Technology-

enhanced materials that make scientific thinking visible can play an important role in both processes” (Kali & Linn, 2008).

In the coming years, computing is expected to be increasingly effective and unavoidably necessary in the processes of science as it is expressed in “Towards 2020 Science” report: “Scientists will need to be completely computationally and mathematically literate, and by 2020, it will simply not be possible to do science without such literacy. This therefore has important implications for education policy right now” (The Science Group, 2006, p.8). In an OECD report entitled “21st Century Learning Environments” the role of schools are specified as follows: “Today, ICT skills – from completing a simple search on the Internet and writing an essay in Word, to cutting a video and designing a Web page – are a prerequisite for entry into the workforce. Schools have an important role to play in providing students with the necessary skills to become tomorrow’s knowledge workers” (OECD, 2006, p.20). In-service science teachers play an important role in creating successful Technology-Rich Environments (TRE) in science teaching and their TPCK confidence is an effective factor to create technology rich science teaching environments

### ***Science teachers’ technological pedagogical content knowledge***

Technological pedagogical content knowledge (now known as TPCK or TPACK) has become a commonly referenced conceptual framework of teacher knowledge for technology integration within teacher education. TPCK is described as complex interaction of content, pedagogy and technology and discussion of successful integration of technology into instruction (Koehler & Mishra, 2008). In recent years researchers described TPCK within the framework Shulman’s (1987, 1986) description of pedagogical content knowledge (PCK). According to Shulman (1986, p.9) PCK “goes beyond the knowledge of subject matter per se to the dimension of subject matter knowledge for teaching” and PCK is the connection and relation of pedagogy and content knowledge. Researchers conceptualized PCK in the domain of teaching with technology under different schemes: “Margerum-Lays and Marx (2003) referred to PCK of educational technology, Slough and Connell (2006) used the term technological content knowledge, and Mishra and Koehler (2006) suggested the term technological pedagogical content knowledge (TPCK) – a comprehensive term that has prevailed in the literature” (as referred to and cited in Angeli & Valanides, 2009, p.155). TPCK can be described as how teachers understand educational technologies and PCK interacts with technology to produce effective teaching with technology.

### ***Aim of the Study***

This study aims to measure in-service science teachers’ TPCK confidence and identify their views about using Technology-Rich Environments (TRE) in science and also we aim to address challenges faced by in-service science teachers creating TRE, give suggestions for successful technology integration in science teaching.

### ***Research questions***

This study will focus on the following research questions:

- I. What are in-service science teachers’ confidence levels on four TPCK constructs (i.e., TK, TPK, TCK, TPCK)?
- II. What are in-service science teachers’ views, needs, and classroom practices about Technology-Rich Environments?

## **METHODOLOGY**

A non-random purposeful sample was used to gather data from in-service science teachers. Ninety-five voluntary public school science teachers participated in this survey. Both quantitative and qualitative research methods were used to investigate the level of TPCK

confidence. The TPCK confidence-science instrument has been adapted into Turkish from Graham, Burgoyne, Cantrell, Smith, Clair and Harris (2009). The instrument was sent to more than 450 in-service teachers by e-mail. 101 teachers' completed and returned the survey, but 6 of them were excluded because of missing data. Additionally, face to face semi-structured interviews were conducted with 4 of the participants. Sample characteristics are summarized in Table 1.

**Table 1. The characteristics of participants**

<b>The characteristics of participants</b>	<b>f</b>	<b>%</b>
<i><b>Gender</b></i>		
Female	44	46.3
Male	51	53.7
<i><b>Teaching hours in a week</b></i>		
10-14	10	10.5
15-19	35	36.8
20-24	38	40.0
25-19	10	10.5
29-34	2	2.1
<i><b>Number of Students in teachers' classroom</b></i>		
Less than 20	10	10.5
Between 21-30	60	63.2
Between 31-40	21	22.1
Between 41-50	4	4.2
<i><b>Teachers' Professional Experience</b></i>		
1-5 years	17	17.9
6-10 years	35	36.8
11-15 years	23	24.2
16-20 years	13	13.7
Upper than 21 years	7	7.4

## RESULTS and DISCUSSION

To address the question of perceived confidence level of in-service science teachers' related to the four TPCK constructs teachers were asked, "How would you rate your own confidence related to task associated?" Twenty-four items along the areas of technological knowledge, technological pedagogical knowledge, technological content knowledge, and technological pedagogical content knowledge of these areas were asked, and the scale for answering consisted of 5 points of confidence. Means were calculated for all items is showed in table 3 and average mean for four sub-factors is showed in table 4. Table 2 shows the ranges of confidence levels formed.

**Table 2. The Ranges Belonging Confidence for Likert Type Scale**

<b>Range Value</b>	<b>Confidence Level</b>
1,00–1,79	not confident at all
1,80–2,59	slightly confident
2,60–3,39	somewhat confident
3,40–4,19	fairly confident
4,20–5,00	completely confident

From the responses of teachers' ranges, minimum, maximum and standard deviation are reported for each item. TPCK sub-factor teachers asserted that they feel somewhat confidence in the 6<sup>th</sup> item "Help students use digital technologies to organize and identify patterns in scientific data", TPK sub-factor they feel somewhat confidence in 4 items "Help students use digital technologies that extend their ability to observe scientific phenomenon", "Help students use digital technologies that allow them to create an0d/or manipulate models of scientific phenomenon", "Use digital technologies to improve communication with students", "Use digital technologies to help in assessing student learning". All items of TCK sub-factor,

teachers asserted that they feel somewhat confidence and TK sub-factor “Create and edit a video clip” item they feel somewhat confidence but two items “Use Web 2.0 technologies” and “Create your own website” they feel slightly confidence.

**Table 3. Summary of Descriptive Statistics Results for the Question, "How Would You Rate Your Confidence in Doing the Following Tasks Associated With Technology Usage?"**

SF	Item	N	Range	Minimum	Maximum	Mean	Std. Deviation
<b>TPCK</b>	4	95	4,00	1,00	5,00	3,66	,918
	5	95	4,00	1,00	5,00	3,42	1,03
	6	95	4,00	1,00	5,00	<b>2,97</b>	1,18
<b>TPK</b>	7	95	4,00	1,00	5,00	<b>3,03</b>	1,11
	8	95	4,00	1,00	5,00	<b>2,84</b>	1,27
	9	95	4,00	1,00	5,00	3,52	1,10
	10	95	4,00	1,00	5,00	<b>3,14</b>	1,13
	12	95	3,00	2,00	5,00	3,51	1,03
	13	95	4,00	1,00	5,00	3,76	1,02
	14	95	3,00	2,00	5,00	3,42	,917
	15	95	3,00	2,00	5,00	<b>3,35</b>	,921
<b>TCK</b>	16	95	4,00	1,00	5,00	<b>3,23</b>	1,04
	17	95	4,00	1,00	5,00	<b>3,10</b>	1,18
	18	95	4,00	1,00	5,00	<b>3,03</b>	1,19
	19	95	4,00	1,00	5,00	<b>3,30</b>	1,04
	20	95	4,00	1,00	5,00	<b>3,21</b>	1,08
<b>TK</b>	21	95	3,00	2,00	5,00	3,90	,911
	22	95	3,00	2,00	5,00	4,22	,865
	23	95	3,00	2,00	5,00	3,70	1,20
	24	95	4,00	1,00	5,00	3,96	1,06
	28	95	4,00	1,00	5,00	3,52	1,25
	29	95	4,00	1,00	5,00	<b>2,77</b>	1,48
	30	95	4,00	1,00	5,00	<b>2,10</b>	1,283
	31	95	4,00	1,00	5,00	<b>2,25</b>	1,20

**Table 4. Summary of Descriptive Statistics for Sub-factors for the Question, "How Would You Rate Your Confidence in Doing the Following Tasks Associated With Technology Usage?"**

<b>Sub-Factors</b>	Number of Items	<b>Scale</b>				<b>Item</b>	
		Min.	Max.	Mean	Std. Deviation	Mean	Std. Deviation
<b>TPCK</b>	3	3,00	15,00	10,06	2,77	3.53	.92
<b>TPK</b>	8	12,00	40,00	26,61	7,35	3.25	.92
<b>TCK</b>	5	5,00	25,00	15,88	4,98	3.18	.99
<b>TK</b>	8	12,00	40,00	26,46	7,38	3.31	.92

From the responses of teachers, they asserted that they feel fairly confidence TPCK sub-factor but somewhat confidence TPK, TCK and TK sub-factors. Teachers feel least confidence TCK sub-factor items that mean they cannot use the educational technologies for a specific topic and get difficulties while relating technology and content, in their science instruction. Vice versa, they feel somewhat confidence knowledge about how to use technology and also to teach more effectively with technology, help students meet any specific curriculum content to use technologies appropriately in their learning. “In other words, merely knowing how to use

technology is not the same as knowing how to teach with it” (Mishra, & Koehler, 2006). Teachers feel most confidence in their ability when teaching science with technologies (TPCK) (Graham et al, 2009).

The second research question was “What are the in-service science teachers’ views, needs, and classroom practices about TRE?” in order to find an answer to this question 5 questions were asked to 95 in-service science teacher and semi-structured interviews were conducted with 4 teacher

**Table 5 Descriptive Statistics of Teachers’ Views about TRE in Science**

<b>Computer facilities</b>	<b>f</b>	<b>%</b>
<b><i>Computer facilities at the school</i></b>		
None computer at school	6	6.3
One computer each class	28	29.7
Computer Lab. at school	41	43.2
One computer used for several class	20	21.1
<b><i>Hours in a week computer-based instruction</i></b>		
1	17	17.9
2	33	34.7
3	17	17.9
4	11	11.6
More than 4	17	17.9
<b><i>Group of class in computer-based instruction</i></b>		
One computer each student	5	5.3
One computer for two students	8	8.4
Small groups	11	11.6
Whole class	71	74.7
<b><i>Computer based instruction years</i></b>		
0	10	10.5
1-5	72	75.7
6-10	13	13.8
<b><i>Need professional development using computer for instruction in science</i></b>		
Yes	74	77.9
No	21	22.1

Responses to the questions about TRE teachers asserted that computer facilities at their schools are not well enough to create a TRE so they generally give computer-based instruction to whole class and approximately all the teachers need a professional development about how to use the computers in science instruction. There is a need for providing technological pedagogical content knowledge confidence to in-service science teachers in order to create optimally functioning technology enhanced classrooms. Some recent studies focused on the barriers effecting technology integration such as limited access to internet, classroom size, and lack of teachers’ knowledge about successful technology integration into instruction (Çakır & Yıldırım, 2009; Cure & Özdener, 2008). Also some other researches indicate that PD program have positive impacts to on teachers’ development of TPACK (Guzey & Roehrig, 2009; Graham et al. 2009; Varma, Husic & Linn, 2008) and can help teachers successfully, integrate technology into their practice (Niess, 2005; Harris, Mishra & Koehler, 2009).

Interviews were conducted with 2 male and 2 female science teachers. Four questions were asked in order to understand how they create a TRE in science instruction. The following four questions were asked during the interviews:

- i. For what purposes do you use computers in teaching science?
- ii. What are the barriers to the TRE in teaching science?
- iii. How do you currently use computers to support your science teaching?
- iv. How do you create a TRE in science teaching?

Teachers asserted that they use computers for showing animations, simulations, watching videos, films, making representations with power point during their instruction. The barriers to TRE were; no access to internet at schools, difficult to find and do technology rich materials such as animations, simulations, video for every subject, creating TRE needs good planning and preparing before the class, having classroom management problems. Teachers tend to group TRE for whole class and show the animations, simulations, video by the projector. They asserted that they sometimes stop the video or animation and ask questions to the class about the subject. One teacher described current use of computers in his science instruction as follows:

*I usually use animations or videos form instruction. It is difficult to find visualizations for every subject in science since most science subjects are abstract. I have to spend time and prepare in order to create technology rich science lessons. However, students in my class are highly motivated when I use visualizations in my science teaching. In the last lesson, I used a cartoon animation of blood cells in my class. The whole class watched the animation together and solved a puzzle after the animation. However, sometimes watching a video or animation in a science lesson cannot be different from watching a movie at the cinema.*

Another teacher described her technology rich class as follows:

*I use a projector when I am using computer in my class. I arrange student's seats in the best way for them to see the whiteboard. I start the lesson with brainstorming about the subject then we watch a video or animation. I do not usually have classroom management problems because students are highly motivated when they are watching a video or animation. However, sometimes students find their peer's questions ridiculous or foolish.*

## CONCLUSION

This study shows that in-service science teachers do not have TPCK confidence sufficient to create a TRE in science teaching. They need professional development about how to use TRE in science teaching. Teachers need to have confidence to use technology as enrichment not as a replacement in science teaching. Koch (2005, p.25) emphasizes that technology cannot alone help students learn science. As she explains a computer can become a part of the science learning experience, if the child feels a need to use it in learning and such a need can be created for example while exploring what causes different weather conditions. In this case students can easily access to some weather reports from the Internet. This act makes the computer a useful and meaningful tool in learning. Such use can also be found in many other computer applications (e.g. certain software packages and online resources) that allow students to explore science phenomena in a simulated environment. Access to interactive manipulation of the simulated phenomena, in a way, forms a science laboratory that allows the child to study and learn in her/his convenience. Successfully integrating technology into science education heavily relies on the development of well-built, coherent professional development programs that are designed with a clear understanding of how teachers need to use technology in their class in the most effective way.

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# INTEGRATING TECHNOLOGY INTO PRE-SERVICE PHYSICS TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE

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**Abstract:** New physics teachers should be equipped with competences for successful integration of technology in the classroom. As an extension of Shulman's PCK (Pedagogical Content Knowledge), teachers need to learn how technological tools can transform pedagogical strategies and content representations for teaching specific topics. The paper reports on the integration of selective teacher training materials, which were used through a blended learning course for pre-service physics teachers. Focusing on the development of Technological Pedagogical Content Knowledge (TPACK) the study examines how pre-service teacher candidates used computer-based technology, to enhance their lesson plans, by selecting appropriate technology tools from the course materials of a European funded project and creating learning opportunities for students. The pre-service candidates' questionnaires, lesson plans and reflection journals were sources of data. Data were analyzed, incorporating both quantitative and qualitative techniques, to determine the effectiveness of the course materials and the course design on pre-service physics teachers' development of TPACK. The training materials appear to stimulate pre-service physics teachers' thinking about useful instructional technological strategies and helped in promoting the development of their Technological Pedagogical Content Knowledge. The findings of the study highlight a need for future research on the development of teachers' TPACK.

**Keywords:** Pre-service physics teachers, computer-based technology, integrating technology, development of TPACK, blended learning course

## THEORETICAL BACKGROUND

Research literature on computer-supported learning suggests the consideration of two important aspects. Firstly, due to the diversity of disciplines and unique features of technology, the ways in which technology might best be used for each discipline strongly depend on the content to be taught [3]. Secondly, the extension of Shulman's concept of "pedagogical content knowledge" to "technological pedagogical content knowledge" (TPACK) [7] emphasizes the critical role of the teacher as curriculum designer. It follows that realizing the potential of the technology requires skills not just of technology, pedagogy, and content in isolation but rather of all three taken together. TPACK is primarily achieved when teachers know how technological tools can transform pedagogical strategies and content representations for teaching specific topics [6].

According to the conceptual framework of Sandholtz, Ringstaff & Dwyer [9] teachers have to move through an evolution of thought and practice when learning to use technology in the learning process. They should start in the so-called 'entry-phase' and end up in the 'invention-phase' discovering new uses for technology tools and using technology as a flexible tool in the classroom to facilitate the emergence of new teaching and learning practices. At a typical entry-level, the teacher uses direct instruction and whole class activities to deliver content and skills to the students. In a classroom of a teacher at innovation (or invention)-level, students are engaged in using technology to do things that could not be done without it.



Researchers and practitioners have been seeking reliable and valid ways to measure the constructs associated with the TPACK framework. Harris and her colleagues [4] promote in amendment of published self-report surveys for assessing TPACK an instrument that supports a performance-based evaluation of TPACK, enabling a triangulation of self-report data and external assessments. Their “TPACK-based technology integration assessment rubric” should support teacher educators to more accurately assess the quality of technology integration in their students’ lesson plans by reflecting on four dimensions: Curriculum-based technology use, using technology in teaching/learning, compatibility with curriculum goals & instructional strategies, fit of content, pedagogy and technology together.

## **RATIONALE**

Recent reviews of the effects of ICT in science lessons show that teachers do not yet exploit the creative potential of ICT and do not engage students enough in the production of knowledge [1]. Therefore teachers need training and continuing professional development in the use of ICT to carefully integrate ICT into the teaching process and to provide appropriate guidance [5]. Actually, ICT-rich environments already provide a range of affordances to enable learning of science [11]. Researchers suggest that integrating these affordances with other pedagogical innovations provides even greater potential for enhancement of student learning [2]. Therefore, supporting the professional development of pre-service teachers for technology integration seems to be an important issue for teacher education.

The context of this study was a teacher education course, aiming at helping prospective teachers to develop abilities to integrate technology with content and pedagogy. Teaching materials developed within a European project and adapted for the education method course, covered three different physics topics: “Cooling & change of state”, “basic electricity concepts” and “motion & forces”. For each topic, up to three types of activities, exploiting the use of ICT to stimulate thinking and promote understanding of basic physics concepts, were offered: Data-logging, simulation and modelling.

The purpose of the study was to investigate prospective teachers’ development of TPACK attempting to address two broad questions:

1. Is there a relationship between the perceptions of the learning environment, motivational orientations and the self-reported evolution of TPACK?
2. Are self-reported knowledge gains in TPACK in agreement with external assessment of teachers’ own lesson plan designs?

## **METHOD**

### **Participants and Setting**

The participants of the study included 17 prospective teachers (9 female, 8 male); all were novices in the field of technology integration in physics teaching and learning. The course was designed as blended-learning course lasting 16 weeks throughout a whole semester. For communication and collaboration as well as for the distribution of the training materials and the questionnaires an electronic platform, based on the software Moodle, was used. There were three 4-hour in-class units in the weeks 1, 6 and 10, during which the prospective teachers were offered opportunities to learn from and not about teaching with technology (see table 1). By means of self-study materials, prospective teachers had to work on individual assignments, designing lesson plans for each of the three topics (cooling & change of state,

basic electricity concepts, and motion & forces), and deliver them to the instructor. The elearning-part of the course enabled prospective teachers to share and discuss their ideas.

Week	Components	Methodology
1	Class session introducing data-logging activities	The initial class session introduced data-logging activities (analysing motion, free fall, accelerated trolley, rebounding trolley and current and voltage for a tungsten bulb) with opportunities for practical work resulting in collecting data.
2 - 5	Individual assignments using on-line resources for video and data-logging	In the succeeding weeks students worked autonomously, obtaining the module and software resources through the <i>Moodle Virtual Learning Environment (VLE)</i> . Through self-study, students learned to analyse video capture data and then chose a topic for which they were required to design a lesson plan featuring the use of video measurement or data-logging.
6	Class session introducing modelling activities	In the second class session, students were introduced to modelling activities featuring the same topics as the first data-logging session.
7 - 9	Individual assignments using on-line resources for modelling	During weeks 7 to 9, students engaged in a further self-study assignment concluding with designing another lesson plan on a chosen topic. This time students were also expected to communicate with each other through the forum within the VLE, exchanging ideas and comments on each other lesson designs.
10	Class session	The third class session introduced simulation activities from the chosen modules.
11 - 14	Individual assignments	During the next weeks of self-study, students engaged in a third lesson design assignment on a chosen topic, exchanging ideas through the VLE forum as previously.
15 - 16	On-line discussion	In the final two weeks students were required to use the VLE forum to discuss with colleagues the potential learning benefits of integrating the ICT activities into physics teaching.

*Table 1. Components and methodology of the course*

## Data Sources

The scales and items for assessing prospective teachers' motivational orientations and their perceptions in TPACK domains were primarily drawn from literature [8; 10] and accordingly adapted. A motivation questionnaire was administered in week 1, whereas a TPACK questionnaire was completed twice, as initial one and at the end of the semester. Additionally each of the participants of the study prepared a reflective journal on the overall process of the course at the end of the semester as well as three lesson plans at specified dates.

## Data Analysis

Responses from the TPACK questionnaire were analyzed as matched-pair means for each survey question. The quality of technology integration was assessed by means of the

Technology Integration Assessment Rubric (see figure 1), which is based on the frameworks of Sandholtz and Harris and their colleagues [4, 9].

Criteria	Adopt	Adapt	Appropriate	Invent
Curriculum Goals (CG)	Technologies are not aligned with CG	... partially aligned with CG	... aligned with CG	... strongly aligned with CG
Instructional Strategies (IS)	Technology use does not support IS	... minimally supports IS	supports IS	... optimally supports IS
Technology Selections (TS)	IS are inappropriate given CG & IS	marginally appropriate	appropriate, but not exemplary	... exemplary
"Fit" TPACK	Content, IS and technology do not fit together	fit together somewhat	fit together	fit together strongly

Figure 1. Technology Integration Assessment Rubric<sup>1</sup>

Also, the relationship among motivational orientations, perceived TPACK and pre-post-difference as well as the quality of TPACK inferred from the lesson plans was analyzed. As the primary method of data examination for the reflective journals and the open questions verbal inductive analysis was used. Accordingly, the data were assigned to four categories, resulting in a numerical overview of the outcomes. All items of the questionnaires were aligned on a Likert scale, ranging from 1, "I totally disagree" to 4, "I totally agree".

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## RESULTS

The findings of the study indicated that prospective teachers value the course materials as well as the design of the course to be helpful for developing a critical understanding of TPACK, independently from gender and motivational orientations. Prospective teachers' goals and value beliefs for the course seem to have a positive impact on the evolution of TPACK, both inferred from self-reports and the external assessment of the associated lesson plans.

A cluster analysis (see figure 2 and table 2) of the motivational scales shows that the participants of the study can be arranged to three groups: 29% (CL1) report high estimates for goal orientation, content task value, self-efficacy, and control of learning beliefs. Whereas

<sup>1</sup> Based on the conceptual frameworks of Sandholtz and Harris and their colleagues

47% of the students in CL 3 are confident in their abilities for accomplishing and performing the future tasks and report rather high values for control of learning beliefs, they are not so highly intrinsically, but more extrinsically, motivated and additionally, not convinced about the importance and usefulness of the course.

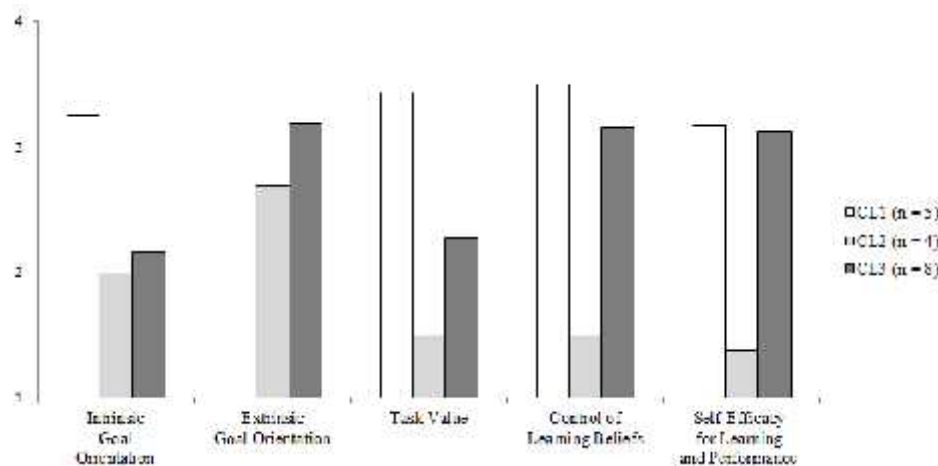


Figure 2. Motivational orientations of the pre-service teachers

24% of the students in CL2 can be described as students with motivational strategies clearly underneath the mean. They report considerable low estimates for their task value, their control of learning beliefs, and their self-efficacy for learning and performance. Furthermore, their ratings for intrinsic as well as extrinsic motivation are also significantly lower than the reference values of group CL3.

	M <sub>CL1</sub>	SD <sub>CL1</sub>	M <sub>CL2</sub>	SD <sub>CL2</sub>	M <sub>CL3</sub>	SD <sub>CL3</sub>
Intrinsic goal orientation	3.25	0.53	2.00	0.88	2.16	0.82
Self-efficacy for learning and performance	3.18	0.09	1.38	0.00	3.13	0.93
Content task value	3.43	0.17	1.50	0.00	2.27	0.94
Number of students	5		4		8	

Table 2. Descriptive statistics of motivational strategies

As illustrated in figure 3, there is also a relationship between motivational orientations and evolution of TPACK. The grey bars in figure 2 correspond to the pre-post-differences of perceived TPACK; the white bars represent the quality of technology integration derived from the lesson plans. The values illustrate the level reached in percentages of the maximum, related to four on the used Likert scales. For example, students in CL1 estimated their TPACK increase to 73% of the maximum and the quality of their lesson plans were rated to reach 67% of the maximum.

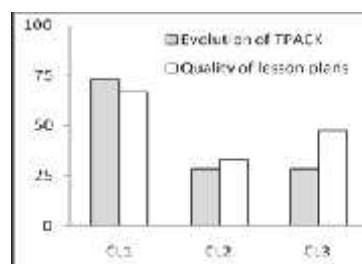


Figure 3: Evolution of TPACK

In addition, ANOVA (see table 3) shows that there is also a significant difference between the groups' mean scores concerning the quality of the corresponding lesson plans (F value = 10.399, significance value = 0.002). For example, students in CL1 attain 14 points on average out of a maximum of 16 points for their third lesson plans, whereas students from group 2 only reach a mean score of 6 points.

ONEWAY ANOVA					
Mean Level of TPCK evolution					
	Sum of squares	df	Mean Square	F	Sig.
Between Groups	160.809	2	80.404	10.399	.002
Within Groups	108.250	14	7.732		
Total	269.059	16			

Table 3. ANOVA for the relationship 'affiliation to a certain cluster and quality of lesson plans'

## CONCLUSIONS AND IMPLICATIONS

In conclusion, this study provides empirical evidence about the impact of the training materials and the course design on prospective teachers' TPACK in particular topics of physics subject matter. Thereby, the development of TPACK is closely related to the motivational orientations of the pre-service teachers. In consequence, it appears reasonable to focus both on issues to motivate pre-service teachers and on certain content topics for highlighting the pedagogical value of the specific use of technologies for understanding physics concepts.

In order to make future teachers capable to attach importance to their crucial role in the learning process of students, especially when ICT tools are introduced, the need for reinterpreting this role becomes an essential demand in teacher preparation programmes aimed at promoting the use of ICT. To provide vision of, how the teacher's role can influence the successful outcome of ICT activities in science education, should be a chief rationale of educational technology training courses. Indeed, before examining the principles underpinning the teacher's role, it is appropriate to review the potential learning benefits associated with the four software tools which serve constructional activities in physics: data-logging, modelling, simulation and video measurement.

However, there is a clear need for future research on how to best design teacher education programs in preparing future educators for the challenge of teaching in the 21st century. Teacher education programs should certainly focus on developing TPACK to enable teachers firstly, to identify their crucial role in using educational technologies in the classroom, and secondarily, to design computer-assisted learning activities which offer guidance as well as room for individual exploration. The teacher's role is critical in structuring tasks and interventions in ways which prompt pupils using ICT to think about underlying concepts and relationships and to find the right way of instruction and level of complexity. Therefore, future research programs should be aimed at both developing teachers' TPACK and evaluating teacher training programs by observing classroom activities and assessing student outcomes.

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